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Edited for the Council by J. LAURENCE PRITCHARD, Hon. Fellow

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NOTICES

Elections

The following members were elected at a Council Meeting held on May 10th, 1927 :—

Associate Fellows.—Major C. J. P. Ball, D.S.O., M.C.; Squadron Commander J. Bird, R.N. (retired), M.I.N.A.; Mr. L. Cullis, M.A.(Cantab.); Brigadier-General P. R. C. Groves, C.B., C.M.G., D.S.O.; Mr. H. J. Penrose; Captain K. N. Pearson, M.C.

Associates.—Mr. R. E. Bissell, Mr. J. V. Bowring, Mr. A. G. H. Diamond, Mr. F. A. Kappey, Mr. E. S. Olney, Mr. J. Pettitt-Herriot, Mr. P. J. Taylor, and Colonel L. M. Wilson, C.M.G., D.S.O.

Members.—Mr. C. H. Jinman, Mr. J. Foster King, C.B.E., and Brigadier-General the Lord Thomson of Cardington, C.B.E., D.S.O.

Council Meeting

A Meeting of the Council was held on Tuesday, May 10th, 1927. Present: Colonel The Master of Sempill in the chair, Captain P. D. Acland, Sir Sefton Brancker, Mr. Griffith Brewer, Wing Commander T. R. Cave-Browne-Cave, Sir Mackenzie Chalmers, Mr. A. E. L. Chorlton, Mr. J. E. Hodgson, Mr. W. O. Manning, Major R. H. Mayo, Lieutenant-Colonel M. O'Gorman, Mr. T. O. M. Sopwith, Dr. H. C. Watts and Mr. R. McKinnon Wood.

Honorary Treasurer

Major D. H. Kennedy, O.B.E., Fellow, has accepted the invitation of the Council to act as Honorary Treasurer.

Chairman

By the unanimous vote of the whole Council, Colonel The Master of Sempill, the present Chairman, was elected for a further term of office, from October, 1927, to September, 1928. The Council passed a vote of thanks for the immense amount of work he had already done on behalf of the Society.

Toronto University Centenary Celebrations

In response to the invitation of Toronto University for the Society to send delegates to the Centenary Celebrations, the following nominations were made :—Professor J. H. Parkin, of Toronto University, Fellow, and Wing Commander E. W. Stedman, O.B.E., Fellow.

The Edward Busk Memorial Prize

A prize of £20 each has been awarded to Mr. L. W. Bryant, B.Sc., Associate Fellow, and Mr. S. B. Gates, for their joint paper on "The Spinning of Aeroplanes." A special letter of commendation together with a grant of £10 from the same fund have been sent to Mr. E. G. Richardson, M.Sc., Ph.D., for his paper on "Recent Model Experiments in Aerodynamics."

Intending competitors for the Prize for 1927 should send their names to the Secretary on or before September 30th. The closing date for the receipt of papers will be December 31st, 1927. Full particulars of the regulations for the Prize can be obtained from the Secretary.

Associate Fellowship Examination

The following is an extract from a letter sent by Mr. C. R. Fairey, Fellow of the Society, to the Chairman, dated April 13th, 1927 :—

> " With regard to Membership, I have for some time made it a rule here among the Technical Staff that for anyone who will sit for the Associateship Fellowship Examination and pass it I will pay the whole expenses plus entrance fee and one year's subscription."

On receipt of this letter the Secretary wrote to the heads of the chief designing firms of the country and asked them if they would be willing to follow Mr. Fairey's generous lead. The following have intimated that they will do so :—

Mr. T. O. M. Sopwith, of the H. G. Hawker Engineering Co. Ltd.
Commander J. Bird, of the Supermarine Aviation Works.
Mr. Siddeley, of Sir W. G. Armstrong Whitworth Aircraft Ltd.
Captain C. C. Walker, of the De Havilland Aircraft Co. Ltd.
Mr. Thomas, of the Bristol Aeroplane Company Ltd.

A number of others have intimated that they have Mr. Fairey's suggestion under consideration and will be prepared to consider it or some modification of it.

Provided that a sufficient number of entries are received the Society's examination for candidates otherwise not qualified for Associate Fellowship will be held during the third week of September. Intending candidates should forward their entry forms as soon as possible, and in any case before the third week of August.

Donations

The Council desire to acknowledge gratefully the following presentations to the Library :—From Mr. J. E. Hodgson, " The First Flight Across the Polar Sea," by R. Amundsen and L. Ellsworth ; " Aerofoil and Airscrew Theory," by H. Glauert, from Mr. R. F. R. Pierce ; a quantity of pamphlets and Reports of the Aeronautical Society from Mrs. Crosland Taylor, and back numbers of the Journal from Mr. F. W. Hills, Mr. J. Laurence Pritchard, and Mrs. Crosland Taylor. They also wish to thank Mr. Kilburn Scott for presenting to the Society a framed caricature of aerial vehicles.

Library

The following Reports and Memoranda of the Aeronautical Research Committee have been recently received and placed in the Library :—No. 1014, " An Extension of the Vortex Theory of Airscrews with application to Airscrews of Small Pitch. . . .," by C. N. H. Lock, H. Bateman, and H. C. Townend ; No. 1044, " Full Scale Pressure Plotting Experiments on Hull and Fins of H.M.A. R.33," by Lieut.-Colonel Richmond ; No. 1046, " The Effects of Body Interference on Airscrew Performance," by W. G. Jennings ; No. 1047, " Model Tests of a Combined Slot and Aileron Control on a Wing of R.A.F. 15 Section, Push Forward Type of Auxiliary," by F. B. Bradfield ; No. 1048, " Slot and Aileron Control on a Wing of R.A.F. 31 Section with Various Types of Ailerons," by F. B. Bradfield and A. S. Hartshorn ; No. 1052, " Full Scale and Model Measurements of Lift and Drag of Bristol Fighter with R.A.F. 30 Wings," by A. E. Woodward Nutt, R. G. Harris and L. E. Caygill ; No. 1054, " The Variation in the Fatigue Strength of Metals when Tested in the Presence of Different Liquids," by G. D. Lehmann ; No. 1055, " Tests on Handley Page Aerofoil A.i. and R.A.F. 31," by Messrs. Handley Page Ltd. ;

No. 1056, "Algebraic Formulæ for the Performance of an Aircraft at Full Throttle," by R. S. Capon; No. 1057, "On the Calculation of Stresses in the Hulls of Rigid Airships," by R. V. Southwell; No. 1058, "D. M. Smith's Method for the Determination of the Transverse Frequencies of Vibration of Uniform Beams," by T. W. K. Clarke and V. M. Falckner; No. 1062, "Dopes and Detonation, Second Report," by Prof. H. L. Callendar; No. 1067, "On the Contraction of the Slipstream of an Airscrew," by H. Glauert; No. 1069, "On a Modification of the Chattock Gauge, Designed to Eliminate the Change of Zero with Temperature," by W. J. Duncan; No. 1070, "Wind Tunnel Test of Aerofoil M.2," by H. Davies and F. B. Bradfield; No. 1071, "Wind Tunnel Tests of Aerofoil R.A.F. 34," by H. Davies; No. 1073, Full Scale Measurement of Lift and Drag of a Bristol Fighter with Slotted Upper Wings and Standard Lower Wings," by J. K. Hardy; and No. 1074, "Full Scale Tests of a Suspended Air Log," by J. K. Hardy.

The following books and pamphlets have also been received:—"The First Flight Across the Polar Sea," by R. Amundsen and L. Ellsworth; "The Effect of Fluctuations of the Gulf Stream on the Distribution of Pressure," by C. E. P. Brooks; "The Variation of Meteorological Elements at St. Helena," by C. E. P. Brooks; "Hourly Character Figures of Magnetic Disturbance at Kew . . .," by J. M. Stagg; Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochshule Aachen; Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen, Lieferung III.; Report of the Progress of Civil Aviation (April, 1926—December, 1926), by the Air Ministry; A.P. No. 859 3rd Edition, "Eagle VIII. and Falcon III. Aero Engines"; A.P. 904, Permanent Commissions in the R.A.F.; "Engineering Abstracts from the Current Periodical Literature of Engineering and Applied Science, Published outside the United Kingdom," by various authors; "The Parachute Salvator," by Lt. Freri; "Industrial Arts Index," Vol. XIV.; "Some Observations on the Flight of Seabirds," by F. W. Jones; "A Note on Bumpiness at Cranwell," by W. H. Pick; "Subject Index to Periodicals, 1922, K. Science and Technology"; Technische Berichte, Translations of, originally published by the Technical Section of German Military Aeronautics, Berlin, 1918; The Carnegie United Kingdom Trust Thirteenth Annual Report; "Proceedings," Vol. II., 1926, of the Institution of Mechanical Engineers; "Aeolus, or the Future of the Flying Machine," by Major O. Stewart; and "Air Facts and Problems," by Lord Thompson.

Royal Air Force Display

Their Majesties the King and Queen hope to be present at the Royal Air Force Display at Hendon on Saturday, July 2nd.

The importance of booking early is urged in view of the greatly increased attendance last year, when 75,000 spectators witnessed the air pageant from within the aerodrome.

The boxes which seat six are limited in number. Those near the Royal Enclosure are £7 and £5, others are £4. In the 10/- enclosure a grand stand has been erected to seat 3,000. There is no extra charge for accommodation in the stand this year. Facilities in the 5/- and 2/- enclosures have also been improved. Tickets can also be obtained direct from the Secretary, Royal Air Force Display, Uxbridge.

The programme this year will contain important new features and the number of aircraft taking part has been increased to nearly 200, probably the largest concentration of aeroplanes assembled at any time since the war.

Council Dinner

The Chairman and Council of the Royal Aeronautical Society, following on the delivery of the Wilbur Wright Memorial Lecture by Professor Prandtl, the

famous scientist from Göttingen University, at the Royal Society of Arts, on Monday, May 16th, gave a dinner in his honour at The Athenæum, at which the following were present :—

The Guest of Honour: Professor L. Prandtl.

President: Air Vice-Marshal Sir W. Sefton Brancker, K.C.B., A.F.C.

Chairman: Colonel The Master of Sempill, A.F.C., A.F.R.Ae.S.

Members of Council: Captain P. D. Acland; Mr. A. E. L. Chorlton, C.B.E., M.Inst.C.E.; Mr. C. R. Fairey, M.B.E., F.R.Ae.S.; Major A. R. Low, F.R.Ae.S.; Mr. F. Handley Page, C.B.E., F.R.Ae.S.; Mr. R. McKinnon Wood, M.I.Mech.E., F.R.Ae.S.; Mr. H. E. Wimperis, O.B.E., F.R.Ae.S.; Mr. Griffith Brewer, F.R.Ae.S.; Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S.; Captain G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.; Mr. J. E. Hodgson; Mr. H. B. Irving, A.F.R.Ae.S.; Major R. H. Mayo, O.B.E., F.R.Ae.S.; Lieutenant-Colonel M. O'Gorman, C.B., D.Sc., F.R.Ae.S.; Mr. T. O. M. Sopwith, C.B.E., A.F.C., F.R.Ae.S.; Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.; Mr. H. C. Watts, D.Sc., F.R.Ae.S.; and Mr. J. Laurence Pritchard, Hon. F.R.Ae.S., Secretary.

Guests of the Council: Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S.; Mr. H. Glauert, M.A., F.R.Ae.S.; Sir Richard T. Glazebrook, K.C.B., F.R.S., F.R.Ae.S.; Air Vice-Marshal Sir John Higgins, K.B.E., D.S.O., A.F.C.; Professor F. W. Lanchester, M.Inst.C.E., Hon.F.R.Ae.S.; Sir Francis McClean, A.F.C., A.F.R.Ae.S.; Mr. R. V. Southwell, F.R.S., F.R.Ae.S.; and Herr Dieckhoff, Counsellor of the German Embassy, representing the German Ambassador.

PROCEEDINGS

SECOND MEETING, SECOND HALF, 61ST SESSION

The second meeting of the second half of the 61st Session was held at the Royal Society of Arts, 18, John Street, Adelphi, on Thursday, January 20th, 1927, when Mr. H. Glauert, Fellow, read a paper on "The Theory of the Autogyro."

Colonel the Master of Sempill, A.F.C., Chairman of the Society, presided.

Colonel SEMPILL: Ladies and Gentlemen,—The autogyro was the subject of a lecture, the first of its kind, before the Society rather over a year ago, when a paper prepared by the distinguished inventor, Senor de la Cierva, was read by our Chairman of the time, Sir Sefton Brancker. Since then developments have taken place and we are fortunate in having Mr. Glauert this evening to read a paper on the theory of the autogyro.

Mr. Glauert needs no introduction to you. His reputation in aerodynamics is international as you well know.

The papers which have been handed round are copies of a letter sent to me by Senor de la Cierva as his contribution to the discussion. He excuses himself from coming to speak in person on the grounds of his difficulty in speaking English. I have had these copies circulated so that you may appreciate his views and so that time during the discussion may be saved.

I will now call upon Mr. Glauert to read his paper.

THE THEORY OF THE AUTOGYRO

BY H. GLAUERT, M.A., F.R.AE.S.

It is now over a year since the Society had the pleasure of listening to Senor de la Cierva's paper* on the development of his new type of aircraft. In view of that paper it is unnecessary for me to enter into any detailed historical account, but I would like to recall to your minds just these few facts. The object which Senor de la Cierva had in view was to design some form of aircraft which would avoid loss of control on stalling and would at the same time facilitate the process of landing. The scheme of using a freely rotating windmill as the lifting surface of the aircraft was tried first in 1919, the device of hingeing the blades at their roots was incorporated in 1922 and the first successful flight of an autogyro followed shortly afterwards in January, 1923. In this country our interest in this novel type of aircraft may be said to date effectively from the demonstration flights carried out at Farnborough in October, 1925. Technical reports describing the characteristics of the autogyro had been available earlier in the year and had led to a theoretical investigation of the behaviour of a freely rotating windmill as a lifting surface. Since that date the theory has been extended in detail and has been applied to predict the probable characteristics of autogyro aircraft or gyroplanes of different types. I have to thank the Air Ministry for permission to read this paper on the theory of the autogyro; I should add, however, that any conclusions I may express as to the merits or limitations of the autogyro represent purely my own personal views on the subject.

* *Jour. Roy. Aero. Soc.*, Jan., 1926.

In presenting the theory in the form of a lecture I am met with the difficulty that the mathematical expressions are of an involved character, and are quite unsuitable for reproduction on the screen or blackboard. I have therefore decided to make no attempt to develop the mathematical analysis, but to devote my attention to the physical basis on which the analysis rests and to explain, as far as possible, any analytical results in terms of the physical facts which they represent. Having thus justified qualitatively the general results of the theoretical investigation, I shall proceed to discuss the conclusions which can be drawn from the theory. I also propose to discuss the various aspects of the problem in the order which is most convenient from the physical point of view, rather than in the order in which they are derived from the development of the theory. I shall confine my attention almost wholly to the behaviour of the freely rotating windmill regarded as a lifting surface.

It is evident that the windmill can be designed to rotate in either sense, but in order to avoid any ambiguity, I shall assume throughout that the windmill rotates as a right-handed screw when viewed from below. The motion of the starboard blades about the shaft is then in the same sense as the forward motion of the aircraft. If the windmill were designed to rotate in the opposite sense, it would simply be necessary to interchange the terms " port " and " starboard " whenever they occur.

The force and moment experienced by the windmill will be referred to the centre of the windmill as origin, and it is convenient to resolve the resultant force into the following three components:—

(1) The thrust T along the shaft.
(2) The longitudinal force H normal to the shaft and in the plane containing the shaft and the direction of motion of the aircraft.
(3) The lateral force Y normal to the first two components.

The positive sense of these components will be taken to be respectively upwards, backwards and to starboard where the blades are advancing. Also

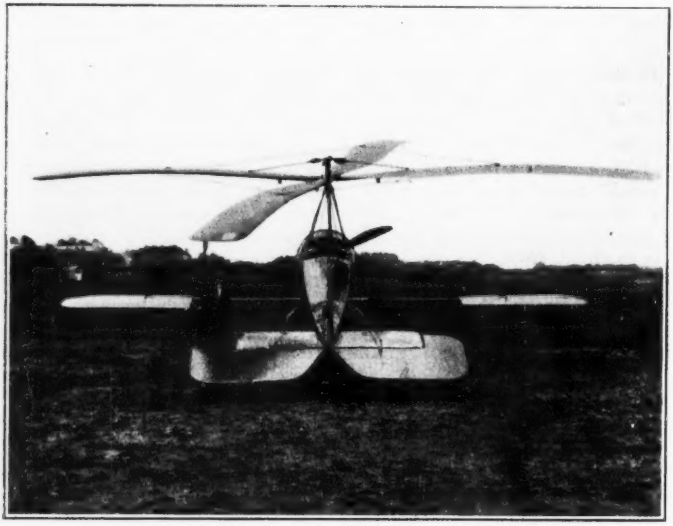


FIG. 1.

the components T and H may be replaced, when convenient, by the lift Z and the drag X defined in the usual manner.

The windmill may have any number of blades greater than two, and these blades will be identical and evenly spaced round the shaft of the windmill. In the Cierva autogyro C6 the plan form of the blades is approximately rectangular, tapering somewhat towards the root and rounded off slightly at the tips, while in elevation the blades are concave downwards. The blades are formed of symmetrical aerofoil sections, set at a small constant angle of pitch θ to the plane normal to the shaft. I have developed my theory on the basis of constant chord c and angle of pitch θ along the blades, but there would be no difficulty in applying the theory to blades with any simple variation of chord and angle of pitch along the radius. I believe, however, that any such small variations would not lead to any appreciable difference in the final results. The two fundamental constants on which the characteristics of the windmill depend are:—

(1) The angle of pitch θ.

(2) The solidity σ, defined as the ratio of blade area to disc area.

If the angle of pitch varies along the radius, θ should be taken to be the mean value over the effective part of the blades. Similarly also the solidity should be taken to be

$$\sigma = Bc/\pi R$$

where B is the number of blades, R the extreme radius and c the mean chord over the effective part of the blades. Thus in the case of the Cierva autogyro C6, the solidity should be calculated from this formula using the full chord, rather than as the actual ratio of blade area to disc area.

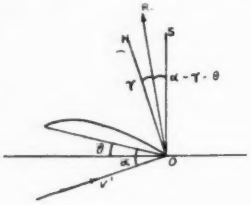
The attitude of the windmill is expressed by the angle of incidence i, which is defined as the backward inclination of the shaft from the normal to the direction of motion, and the motion of the windmill is expressed by the forward speed V of the aircraft and the angular velocity Ω of the blades about the shaft.

The first point to consider is why the windmill rotates at all, or rather why it rotates in the correct sense, for if the windmill were dropped from rest with the shaft vertical it would undoubtedly begin to rotate backwards. On the other hand, if the windmill is at rest and is then subjected to an air current normal to the shaft, the port blades would have higher drag than the starboard blades and rotation would start in the correct sense. A simple method of looking at this question when the windmill is descending vertically, has been suggested by Mr. A. R. Low. Consider an element of a blade at radial distance r and assume that the velocity V' of the air relative to the blade element is inclined upwards to the plane of rotation, so that the blade element is working at an angle of incidence α which is greater than the angle of pitch θ. If ON is the normal to the direction of the velocity V', the resultant force R on the blade element will be inclined backwards at the small angle r from ON, r being the gliding angle of the aerofoil section at the angle of incidence α. The resultant force R is inclined forwards at the angle $(\alpha - r - \theta)$ from the line OS, which is parallel to the shaft of the windmill. Now in order that there may be no accelerating or decelerating force on the blade element, the line of action of the resultant force must coincide with OS, and so the condition of steady motion is simply

$$\alpha - r - \theta = 0$$

In Fig. 2 I have drawn the curve of $(\alpha - r)$ against α for the symmetrical section used on the Cierva autogyro C6. The curve is based on model tests of the wing section at $cV = 65$ and corresponds to two dimensional motion or infinite aspect ratio in accordance with modern aerofoil and airscrew theory. It will be noticed that so long as θ is less than 7° there are two values of α which will give steady motion, but only one of these values represents a stable motion. Imagine a small arbitrary increase of incidence due to an accidental reduction in the rate of rotation. For stability of the motion it is necessary that there

shall now be an accelerating force, represented by a positive value of $(\alpha - \tau - \theta)$, and hence the condition for stability is simply that $(\alpha - \tau)$ increases with α.



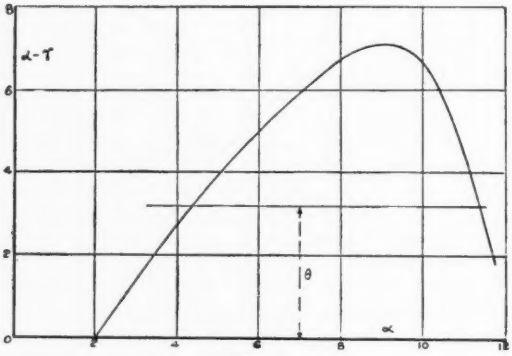


FIG. 2.

For the angle of pitch of 2°, Fig. 2 indicates two steady motions, $\alpha = 3°.5$ and $\alpha = 11°.7$, but only the lower value represents a stable motion. This value corresponds to a lift coefficient of 0.20 of the aerofoil section. Also the resultant velocity V' is composed of an axial velocity u and a rotational velocity Ωr, and in the stable motion we find that

$$u = 0.026\Omega r$$

If we assume that this condition is satisfied along all the blades, it is a simple matter to calculate the thrust of the windmill, and since the thrust supports the weight of the aircraft, we obtain finally for the rate of rotation of the windmill

$$\Omega R = 79.6\sqrt{(w/\sigma)}$$

where w is the loading per sq. ft. of disc area and σ is the solidity of the windmill. This result is in good agreement with the velocity determined in a more accurate manner, but the theory suffers from the defect that it insists on the torque of each blade element being zero instead of using the true condition that the torque of the whole windmill is zero.

The simple theory is very useful for obtaining a first estimate of the rate of rotation and for indicating the important fact that the angle of pitch of the blades must not be greater than 7° if the rotation is to be maintained, while for reasonable stability the angle of pitch should not exceed 6°.

Before passing to the more detailed theory which takes account of the flapping of the blades and of the periodic forces which they experience, I wish to point out that the axial velocity u obtained in the simple theory must not be

confused with the component $V \sin i$ of the air velocity along the shaft. The thrust of the windmill causes an induced velocity or interference, and it follows that the axial velocity u through the disc of the windmill is essentially less than the undisturbed velocity $V \sin i$. One of the chief difficulties of developing a satisfactory general theory is the estimation of this induced velocity, *i.e.*, of the relationship between velocities u and $V \sin i$. I shall return to this point at a later stage, but before doing so I want to consider the flapping motion of the blades and its effect on the aerodynamic behaviour of the windmill.

It is convenient to consider first of all the forces and moments which would be experienced by a windmill with fixed blades. The line of action of the resultant force will be approximately parallel to the shaft of the windmill, and hence the principal force component will be the thrust T, while the longitudinal force H and the lateral force Y will be relatively small. On the other hand, the line of action of the resultant force is always inclined backwards from the shaft and in consequence the best lift-drag ratio of a windmill is inevitably worse than that of an aerofoil, for the line of action of the resultant force on an aerofoil is inclined forwards from the normal to the chord under favourable conditions. A windmill with fixed blades will also experience a rolling moment to port owing to the greater velocity of the starboard blades relative to the air, and it is in order to avoid this rolling moment that the device of hingeing the blades at their roots was introduced. If we ignore the small distance of these hinges from the centre of the shaft, it is evident that the hinged blades cannot transmit any rolling or pitching moment about the centre of the windmill. There will be a resultant force whose line of action passes through the centre of the windmill and there may be a torque about the shaft.

The hinged blades cannot transmit any moment about their hinges, and so, ignoring for the moment any periodic effects, there must be a general upward inclination of the blades through an angle β_0, whose magnitude depends in a rather complex manner on the curvature, weight and moment of inertia of the blades. This upward inclination is required to obtain a balance about the hinge of a blade of the moments due to the thrust, the weight and the centrifugal force. The effect of the weight of the blades is relatively unimportant and to a close approximation the angle β_0 is directly proportional to the thrust moment and inversely proportional to the moment of inertia. The angle β_0 is independent of the angle of incidence of the windmill and in a typical numerical case its value was found to be approximately 6°. It is important that this upward inclination β_0 shall not be too large, since it introduces a dihedral effect on the windmill which will be seen at a later stage to involve increased drag, lateral tilt of the plane of rotation and an inconvenient sideforce. It is uneconomic, therefore, to reduce the weight of the blades indefinitely.

By means of the general upward inclination β_0 of the blades the moment of the centrifugal force balances a constant thrust moment about the hinge of the blade, and it appears in the course of the analysis that the flapping of the blades is equivalent to a tilt of the plane of rotation. Relative to this new plane of rotation there are no periodic centrifugal or inertia moments and it follows that the thrust moment must also have a constant value at all angular positions of the blades. Where the thrust moment would be large in the case of a fixed blade, a hinged blade rises and so causes a reduction of its effective angle of incidence and of its thrust. Thus the starboard blades will be rising and the port blades will be falling, and this motion is equivalent to a tilt of the plane of rotation backwards through an angle β_1, the lowest point of the new plane of rotation being down wind. In addition to this velocity effect, there is a dihedral effect owing to the general upward inclination β_0, by virtue of which the thrust tends to be high in front and low at the back. By the same argument as before, the blades will rise in front and fall at the back, the plane of rotation will be tilted laterally as well as fore and aft, and the new plane of rotation will have

its lowest point somewhere in the first quadrant measured from the downwind position. The angular position of a blade from the downwind position will be noted by the angle ψ, and the lowest point of the plane of rotation by the phase angle ψ_1.

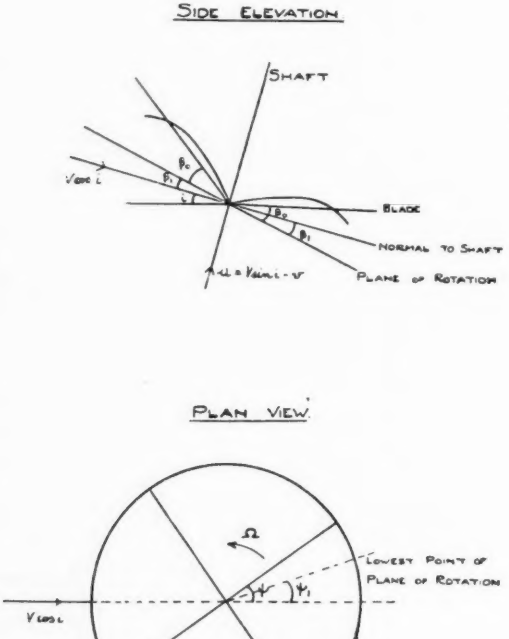


FIG. 3.

The lateral tilt of the plane of rotation depends on the dihedral effect and this can be modified by adjusting the curvature of the blades. With straight blades the full dihedral effect represented by the angle β_0 will occur, but if the blades are concave downwards the dihedral effect will be reduced since the outer parts of the blades will be inclined at an angle smaller than β_0 to the plane normal to the shaft of the windmill. Thus in a typical numerical case the phase angle ψ_1 was found to be 42° for straight blades and only 2° for blades with 3 per cent. camber. More generally it is found that the phase angle ψ_1 can be reduced to zero by choosing the camber of the blade form suitably, the requisite camber increasing with the angle of inclination β_0, but the adjustment will be exact for one angle of incidence only. It is to be noted however, that as the blades are made lighter, the angle β_0 increases and the curvature of the blades should also be increased.

The fore and aft tilt of the plane of rotation depends on the difference of velocity on the port and starboard blades and is therefore proportional to $V \cos i$. The angle of tilt leads to increased drag as compared with an airscrew with

fixed blades and it cannot be eliminated by any modification of the design. Its magnitude is roughly 4° at top speed, and the associated increase of drag is the price which must be paid for eliminating the rolling moment.

The motion of the blades has been discussed in terms of a general upward inclination β_0 and of an angle of tilt β_1. In general, if β is the upward inclination of a blade above the plane normal to the shaft and if ψ is the angular position of the blade from the downwind position, we can express the angle β as a Fourier series of sines and cosines of the angles ψ, 2ψ, 3ψ, etc. I propose, however, to retain only the first harmonics and to neglect all higher harmonics of the blade oscillation. The angle β can then be expressed in the form

$$\beta = \beta_0 - \beta_1 \cos(\psi - \psi_1)$$

where β_0, β_1 and ψ_1 represent respectively the general upward inclination of the blades, the tilt of the plane of rotation, and the angular position of the lowest point of the new plane of rotation.

I pass now to a consideration of the velocity of the air relative to a blade element, which is the first step in the calculation of air force experienced by the blades. Relative to the aircraft a blade has the angular velocities Ω about the shaft and $\dot{\beta}$ about its hinge, while the velocity of the air has the components $V\cos i$ normal to the shaft and $V\sin i$ along the shaft. I have already pointed out, however, that the axial velocity u through the disc of the windmill is less than the undisturbed velocity $V\sin i$ owing to the interference of induced velocity caused by the windmill itself. The determination of this induced velocity or of the relationship between the velocities u and $V\sin i$ is undoubtedly the most fundamental point in the development of the theory of the gyroplane. When this relationship is established in a satisfactory manner, the rest of the work is only rather complicated mathematics or rather tedious arithmetic. To determine this relationship I suggest the following considerations.

Firstly, the momentum equation for an airscrew of radius R giving a thrust T is

$$T = 2\pi R^2 \rho u v$$

where u is the velocity through the airscrew disc and v is the induced velocity at the disc, so that $2v$ is the slipstream velocity.

Secondly, the equation for the normal induced velocity v of an aerofoil of semi-span s with lift L disturbed elliptically across the span is

$$L = 2\pi s^2 \rho V v$$

These two expressions may now be written in the general form

$$(\text{Force}) = 2\ (\text{Mass affected}) \times (\text{induced velocity})$$

and in each case the mass affected is the product of the density, of the area of the circle on the span as diameter, and of the velocity through this circle. The direction of the induced velocity is always opposite to that of the force. This general expression will therefore be taken to apply also to the case of the inclined windmill of a gyroplane. The induced velocity v will be directed downwards along the shaft and its magnitude will be determined by the equation

$$T = 2\pi R^2 \rho V' v$$

where V' is the resultant of the velocities V and v. The axial velocity u is then obtained as

$$u = V\sin i - v$$

and u is therefore known as a function of the thrust T, the velocity V and the angle of incidence i. It may be noticed that the expression for u implies that this velocity has a constant value over the whole disc of the windmill.

The next step is to write down the expressions for the velocity of the air relative to the blade element at radial distance r along the blade in the angular position ψ. I do not propose to enter into the details of these expressions now

as they are of a rather complicated form owing to the upward inclination and curvature of the blade. The component normal to the shaft and to the radial arm is simply $(\Omega r + V \cos i \sin \psi)$ and in general the resultant velocity does not differ greatly from this component, or in other words the resultant relative velocity is inclined at a small angle to the plane of rotation. There is also a periodic radial velocity which I propose to neglect completely. Moreover, I retain only first harmonics of the angular position ψ in the expressions for the velocity components and their products.

These assumptions and approximations are valid for the greater part of all the blades, but they break down near the roots of all the blades and over a wider range of the retiring blades. The root sections of the blades are not of any great importance and no serious error will be introduced by the inaccuracy of the approximations in these regions. On the other hand it is important that the approximations shall not break down too widely over the retiring blades. It is not easy to assign a definite limit to the validity, but as a guide I suggest the limit that the principal velocity component must remain positive over the outer half of the retiring blade. This is equivalent to defining the limit of validity by the condition that the velocity V is not greater than $\frac{1}{2}\Omega R$. The effect of the approximation is almost certainly to overestimate the merit of the windmill, for it is evident on physical grounds that the windmill cannot behave in a satisfactory manner when the forward speed V approaches equality with the tip velocity ΩR. When $V = \frac{1}{2}\Omega R$, half the retiring blade is moving backwards relative to the air and the aerodynamic conditions are very inefficient.

The aerofoil section used on the Cierva autogyro is of a symmetrical form in order to obtain a constant position of the centre of pressure and to avoid torsion in the spar of the blade. It seems probable that symmetrical sections will be used in all future designs, but the use of a cambered section would not necessitate any modification of the aerodynamic theory, provided the angle of pitch θ is measured from the no lift line of the aerofoil section.

The aerodynamic characteristics of the aerofoil section must be taken to correspond to two dimensional motion or infinite aspect ratio in accordance with modern aerofoil and airscrew theory. At small angles of incidence, therefore, the lift coefficient is simply proportional to the angle of incidence and the drag coefficient is very small. I have therefore adopted the plan of replacing the actual drag coefficients, which vary along the blade and from blade to blade, by a mean value δ, and by this device it is possible to develop the analysis in general terms without turning to methods of graphical integration.

These assumptions for the aerofoil characteristics tend to break down in the same regions as the approximations for the velocity relative to the blade element. On the retiring blades the aerofoil sections tend to stall, but owing to the scale effect which is very important on thick symmetrical sections, the assumptions which I have introduced will be more satisfactory for a full-scale windmill than for its model, and any divergence from the theory will therefore tend to decrease as the scale increases.

It is important to realise that the mean drag coefficient δ which I have introduced is essentially greater than the drag coefficient of the aerofoil section at small angles of incidence, since it must take account of the increased drag coefficients which occur on the retiring blades and near the roots of all the blades. As a guide to the choice of the value of δ it is useful to note the mean lift coefficient of the aerofoil sections as given in Table I. These values are calculated by means of results obtained at a later stage of the analysis and show that the mean lift coefficient increases with the angle of pitch θ and with the mean drag coefficient. The drag coefficient of a good thick symmetrical section is of the order 0.004 at a reasonably high model scale. I suggest, therefore, that typical values of the mean drag coefficient δ are probably 0.010 for a model and 0.006 for a full-scale windmill.

TABLE I.
MEAN LIFT COEFFICIENTS.

δ	0.004	0.006	0.008	0.010
$\theta=2^\circ$	0.181	0.205	0.226	0.243
4°	0.261	0.281	0.300	0.317

This concludes the preliminary work and it is now possible to integrate the aerodynamic forces on the blade elements to obtain expressions for the resultant force and torque of the windmill. In free rotation the torque about the shaft is essentially zero, and this condition leads to a simple equation determining the axial velocity u. Writing x for the ratio of the axial velocity u to the tipspeed ΩR, *i.e.*,

$$x=u/\Omega R$$

I find that

$$\delta=4x\,(\theta+3/2\,x)^*$$

and Table II. gives the value of x as a function of θ and δ.

TABLE II.
VALUES OF $x=u/\Omega R$.

δ	0.004	0.006	0.008	0.010
$\theta=2^\circ$	0.0166	0.0220	0.0266	0.0308
4°	0.0115	0.0160	0.0200	0.0237

The interesting point is that the axial velocity u is independent of the forward speed V and of the angle of incidence i, while numerically it is of the order of 2 per cent. of the tip speed.

Although the resultant torque is essentially zero, the torque on the individual blades has a finite value which is proportional to the velocity $V\cos i$ normal to the shaft. To a close approximation it appears that the aerodynamic forces tend to accelerate the retiring blades and to retard the advancing blades.

Passing next to the thrust along the shaft, it appears that although the moment of the thrust of a blade has a constant value, the thrust itself varies periodically. On a retiring blade the thrust is concentrated towards the tip and hence the thrust on the blade is less than on an advancing blade. Similarly, also the dihedral effect due to the upward inclination of the blades causes increased thrust on the front blades, and the combined effect is that the maximum thrust occurs approximately in the angular position $\psi=135^\circ$. The periodic variation of the thrust is proportional to $V\cos i$ and its magnitude is 30 per cent. of the mean value when the forward velocity is equal to half the tip velocity.

The magnitude of the thrust is found to be

$$T/(\pi R^2\rho\Omega^2R^2)=\sigma\,(\theta+3/2\,x)$$

and the typical numerical value for $\theta=2^\circ$ and $\delta=0.006$ is $0.068\,\sigma$. To a close approximation the thrust T must support the weight W of the aircraft, and hence in the special numerical case

$$\Omega R=78.8\sqrt{(w/\sigma)}$$

where w is the loading in lb. per sq. ft. of disc area and σ is the solidity. More generally

$$\Omega R=2\sqrt{(xw/\rho\delta\sigma)}$$

* Angles are of course expressed in circular measure in all formulæ.

The longitudinal force H is derived from several sources. Firstly, the force components which give retarding torque on the advancing blades and accelerating torque on the retiring blades combine to give a positive contribution to the longitudinal force. Next the backward tilt of the plane of rotation through the angle β_1 implies that the thrust is also inclined backwards through the same angle and so gives a component normal to the shaft. Finally the dihedral effect, due to the general upward inclination of the blades through the angle β_0, causes increased thrust on the front blades and adds to the longitudinal force a term proportional to β_0^2.

The final result is very complex when the curvature of the blades is taken into account, but in my calculations I have used an approximation which ignores the curvature of the blades and the dihedral effect.

In a typical numerical case the ratio of the longitudinal force to the thrust obtained from the complete formula was $(0.264\ V\cos i/\Omega R)$. If the curvature of the blades is ignored, the numerical factor falls to 0.209, and the approximate formula gives 0.198. Thus the approximation is not very good, but it is impossible to use the complete expression in general calculations owing to the large number of parameters involved. In any special application, however, it would be advisable to use the complete expression rather than the approximation. On the other hand the drag is

$$X = H\cos i + T\sin i$$

and the error introduced in the value of H by the approximation will be of importance only at small angles of incidence. Moreover, it should be noted that the use of the approximation will result in the drag of the windmill being calculated too low.

The lateral force Y is even more complex in its origin than the longitudinal force, but the analysis reveals the following facts. Firstly, the force components of the torque give a lateral force to port, and secondly the thrust, whose maximum value occurs approximately in the angular position $\psi = 135°$, also gives a contribution in the same sense. In a typical numerical case I found the ratio of the lateral force to the thrust to be $-0.108\ V\cos i/\Omega R$, but with straight blades the numerical factor changed to $+0.005$ owing to the lateral tilt of the plane of rotation to starboard.

The calculated lateral force with curved blades is to port and we should expect therefore that the base of the windmill shaft would be moved to port in order to avoid sideslip of the aircraft. Actually however the shaft was moved to starboard on the Cierva autogyro. This discrepancy suggests that there are some factors which have been neglected in the development of the theory, and I have found the source of the error to be in the assumption that the axial velocity u has a constant value over the whole disc. At small angles of incidence, when the windmill gives rise to a trailing vortex sheet very similar to that of an aerofoil, the induced velocity must increase from front to rear of the disc, and hence the axial velocity u will decrease from front to rear. This variation of the axial velocity is equivalent to an increased dihedral effect, and, in view of what has been said before, results in an increase of the phase angle ψ_1, or a tilt of the plane of rotation to starboard. In consequence there is a positive contribution to the lateral force Y, but fortunately the thrust, torque and longitudinal force are not affected. For a given thrust the induced velocity is inversely proportional to the velocity V, and so also is the corresponding contribution to the lateral force. Thus the lateral force is of the form

$$Y/T = A/V - BV$$

where A and B are constants. The lateral force is to starboard at low speed and to port at high speed. The shaft of the windmill is tilted laterally to suit some mean angle of incidence. At a higher angle of incidence there will be a force to starboard and the aircraft will sideslip and roll over to starboard until

balance is obtained. Similarly at small angles of incidence the aircraft will tend to fly with the port wing down.

The numerical values which are shown in Figs. 4—8 have been derived from this theory. Fig. 4 shows the maximum lift coefficient and the maximum

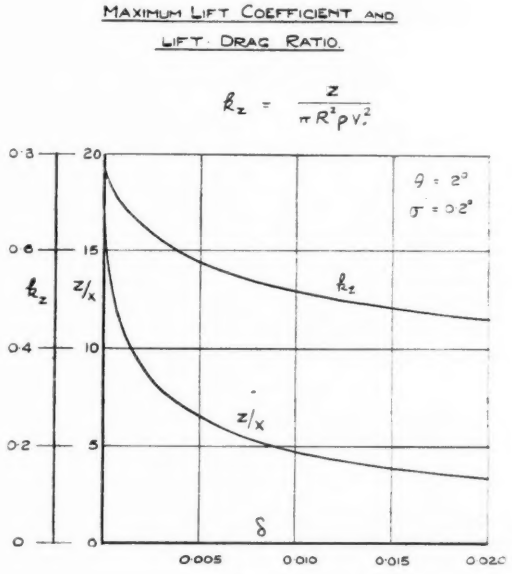


FIG. 4.

lift-drag ratio of a windmill of solidity 0.2 and angle of pitch 2°. Both lift and lift-drag ratio fall as the mean drag coefficient δ increases. With a full scale windmill we may anticipate a maximum lift coefficient of the order of 0.6 and a lift-drag ratio of the order of $6\frac{1}{2}$, while the corresponding values for a model will more probably be 0.5 and $4\frac{1}{2}$. The angle of incidence at which the maximum lift occurs varies from 35° to 40°, increasing as the maximum lift coefficient decreases. When $\delta = 0.006$ the effect of increasing the angle of pitch to 4° is to increase the maximum lift coefficient from 0.56 to 0.63 and to decrease the lift-drag ratio from 5.9 to 5.0. Similarly the effect of reducing the solidity from 0.2 to 0.1 is to decrease the maximum lift coefficient from 0.56 to 0.50 and to increase the lift-drag ratio from 5.9 to 6.5.

Fig. 5 shows full details for a windmill defined by the parameters $\theta = 2°$, $\sigma = 0.2$, $\delta = 0.006$. It is important to note the very flat top of the lift curve, which is one of the great merits of the autogyro system, and its sinuous form at small angles of incidence. Figs. 6 to 8 show in turn the effect of varying the parameters δ, σ and θ. It is desirable of course that the mean profile drag coefficient should be as low as possible. The solidity 0.2 is a good mean value, but a smaller solidity would be desirable for high speed. The angle of pitch of 2° is probably the best unless top speed is to be sacrificed in order to attain the lowest possible landing speed.

The general equations can also be used to calculate the conditions suitable for high speed, and it appears that for any given top speed of level flight there is a best wing loading for which the power absorbed by the drag of the windmill

is a minimum. The results of these calculations are summarised in Table 3. It will be noticed that the limiting condition that V should be less than $\frac{1}{2}\Omega R$ is satisfied in all cases, but the best loading rises as the square of the top speed. Also it is impossible to use a lighter loading since this would give too low a value for the ratio of tip speed to forward speed. Taking the solidity 0.20 as an example, a top speed of 200 m.p.h. calls for a loading of 11 lbs. per sq. ft. of

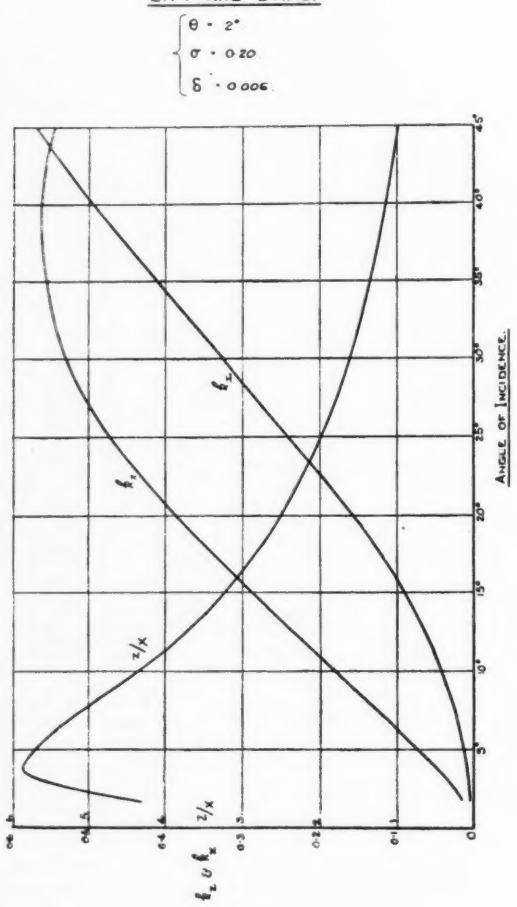


FIG. 5.

disc area or 55 lbs. per sq. ft. of blade area, and the stalling speed, which rises in the same ratio as the top speed, would be 62 m.p.h. With solidity of 0.10, the same top speed would call for a loading of 7.2 lb. per sq. ft. of disc area or 72 lb. per sq. ft. of blade area, and the corresponding stalling speed would be 53 m.p.h. Now an aeroplane loaded 12 lb. per sq. ft. would have a stalling speed

of 63 m.p.h. if the wings have a maximum lift coefficient of 0.6, and so it appears that for high speed aircraft a gyroplane will not land much slower than the corresponding aeroplane, while owing to its greater drag the top speed will be from 10 to 20 m.p.h. lower.

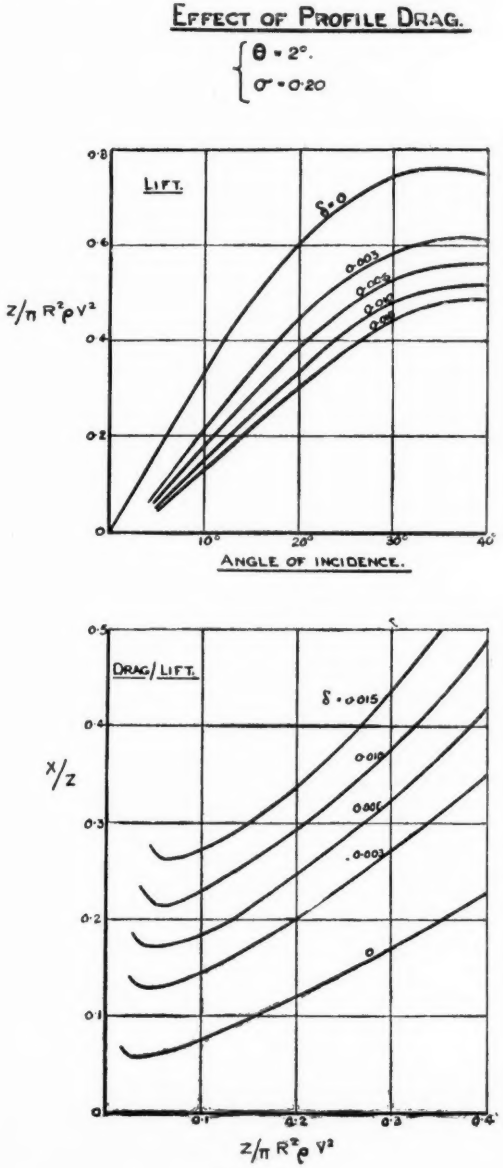


FIG. 6.

In the light of these results, that a high speed gyroplane is slower than the corresponding aeroplane and is incapable of carrying out the characteristic slow landing associated with this type of aircraft, it would appear that the useful field of the gyroplane is confined to those cases where extreme high speed is not

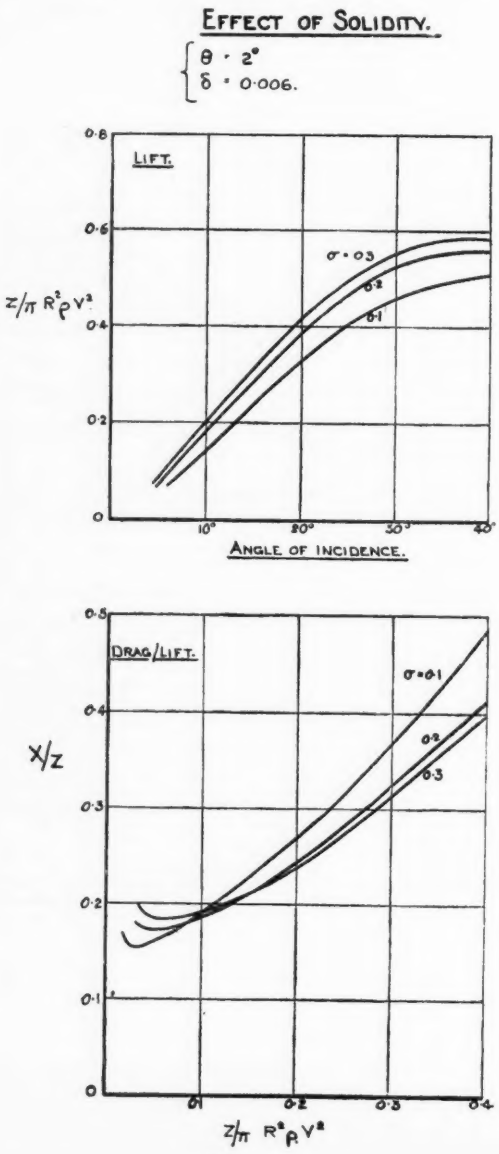


FIG. 7.

required. There are undoubtedly many cases where it is advantageous to sacrifice some degree of top speed and general efficiency in order to obtain ease of landing and safety from the danger of stalling, and it is in these cases that the autogyro system will find its most useful application.

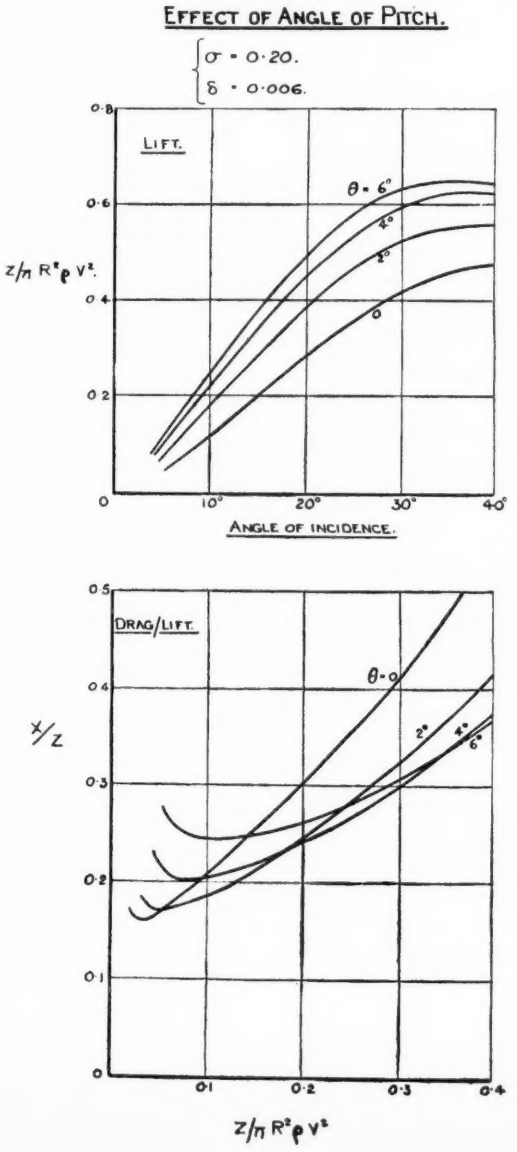


FIG. 8.

TABLE III.
CONDITIONS FOR TOP SPEED.

σ	0.10	0.15	0.20
$\Omega R/V$	2.28	2.12	2.00
$10^4\, w/V^2$	0.84	1.00	1.28

Before concluding I wish to say just a few words about the possibility of the vertical descent of a gyroplane. The condition in which the windmill is then operating is unfortunately outside the scope of airscrew theory at present, and our conclusions must be based wholly on empirical results. In the light of wind tunnel experiments and of dropping tests it appears that the velocity of steady vertical descent of a windmill is of the order of 25 w, where w is the loading per sq. ft. of disc area, and for a loading of 2 lbs. per sq. ft. this means a vertical velocity of 35 f.p.s. I see no reason for believing that the rate of descent of a full scale windmill can be appreciably less than this value, and so I do not believe that it would be safe for a gyroplane to descend vertically to the ground for any considerable height in still air. Of course, with a wind blowing and for a descent from a low height, from which the full vertical velocity would not be attained, it might be possible to perform this manœuvre, but a genuine steady vertical descent at a safe speed does not seem to be possible.

Finally, as to the comparison between theory and experiment, there is unfortunately little reliable evidence available at present. The full scale tests carried out at Farnborough are in general agreement with the theory, but it is not possible to make a critical comparison until more detailed and more accurate experiments have been carried out. Wind tunnel experiments on as large a scale as possible are being carried out at the National Physical Laboratory. The preliminary results obtained agree fairly well with the theory above an angle of incidence of 10°, but below this angle there is a divergence between theory and experiment, the latter indicating a higher drag. This divergence is associated with the scale effect on the blades, since the angle at which it occurs decreases as the scale of the test increases. On the whole I believe that the theory gives a reasonably accurate estimate of the performance which may be anticipated from full scale gyroplanes, and that where the theory errs, it is in the direction of overestimating rather than of underestimating the merit of the gyroplane. On the other hand, the maximum lift-drag ratio occurs at a very small angle of incidence, where the approximations made in the theory become rather inaccurate and where the scale effect on the model tests is large. All that can be said is that neither the full scale tests nor the wind tunnel observations at the National Physical Laboratory give any indication of a lift-drag ratio superior to that suggested by the theory. Improvement in the design of the windmill may lead to better results, but I believe that the gyroplane will always be slightly inferior to the aeroplane for top speed. On the other hand, the gyroplane has the very important advantages of a slower landing speed and of the absence of a sudden and violent stall.

DISCUSSION

Colonel SEMPILL: Although the merits of the autogyro may be open to considerable argument, and will be, no doubt, for some time, there can be no doubt in our minds as to Mr. Glauert's merits as a lecturer, and I know you will wish to congratulate him.

I was hoping that Professor Bairstow would come and open the discussion, but he has written to say that he is extremely busy, and that he has nothing to add to his contribution to the discussion on Senor de la Cierva's paper, printed

in the Journal for January, 1926, in which he pointed out that the autogyro must prove to be less efficient than the aeroplane at high speeds. Senor de la Cierva's paper has doubtless been read by you all.

Major Wimperis, Director of Scientific Research at that time, and still, we are glad to say, said then of this invention that it was by far the most important of the aeronautical inventions of recent years. Whatever may be our opinions of the autogyro, we may congratulate the Director of Scientific Research on his prompt action in bringing this machine over here almost directly after he had heard of it. Generally, Government departments are not famed for quick action, but in this case there is someone at the head who can make things move quickly, and we hope that he will induce other departmental chiefs to act in a similar way, and that he will act in a similar way himself in regard to certain British inventions that require the stimulus of his attentions.

Major Wimperis suggested that a good way to judge the safety of the autogyro was to ask, how could a pilot of such a machine best commit suicide? Sir Sefton Brancker has answered, after consultation with Senor de la Cierva, that no matter what happened he would not be able to do this. As you all know, the reason why British machines have such excellent undercarriages is because our late Chairman was accustomed to test them very thoroughly. As Major Wimperis is so familiar with this subject and has done so much to make it possible for us to see the autogyro, I am going to ask him if he will be good enough to open the discussion this evening. Even if Professor Bairstow's opinion is upheld, it does not of necessity follow that there is no case for the autogyro, as it appears to have other attributes that would under certain conditions more than pay for this. The question of vertical descent or descent at an angle approaching the vertical has given rise to acute argument, on which we should like to hear Major Wimperis.

Major WIMPERIS: We have listened to Mr. Glauert with great interest. We listened to Senor de la Cierva's lecture of a year ago with not only very great interest, but with a great and increasing wonder as he unfolded to us the work which he had accomplished. He brought us a challenge. We had been inclined to look upon rotating wing machines as something rather humorous. The rotating wing machine had exercised its spell over most of the civilised nations of the world, but none of the machines produced could show an efficiency in flight of more than a fraction of that achieved by the autogyro. That was a challenge to our scientific men, and when we saw the machine fly we saw how difficult it would be for the challenge to be met. We saw the windmill going round in what appeared to be the wrong direction. We saw that windmill rotate without mechanical drive at all. Moreover, the wings rose and fell as they rotated. So compared with the fixed wing machine the explanation was bound to be difficult. Mr. Glauert was one of the people who took up the challenge and explained how such a device was likely to behave. He deserves our commendation for having put up as good an explanation as he has. He has explained a great many of the motions of the autogyro. No one living can at present explain them all.

Mr. Labouchere once said that he did not object to Mr. Gladstone having a card up his sleeve, but what he did object to was Mr. Gladstone saying that "God put it there." This machine has a card up its sleeve. Mr. Glauert says *he* did not put it there. When it is making a vertical descent with the power off, it ought, according to the theory, to come down at a certain speed. The machine refuses to come down at that speed. The explanation may be what you will, but provided that the machine always exhibits this characteristic, all will be happy. Those who are engaged in explaining it may not be so happy.

I think this needs to be said. The discussion on the autogyro to-night has been on the autogyro as it is in the early stage at which we have seen it fly, that is, with a wing form that is not likely to persist, and with a constant pitch

angle which the inventor may or may not decide to adhere to. If the structure is changed so that the pitch angle can be varied, the rate of descent will be varied too. Moreover, the present machine has to be started by hand with a rope arrangement. When a self-starter device is fitted, that perhaps may be used not only for starting the windmill, but for getting off the ground, and for certain manœuvres during the flight. These possible improvements have been left out of the discussion, and it is only fair to the inventor that we should realise that there are such possibilities.

I think we already know that in view of the pilots who have flown it, it is an easy machine to fly. That must be set against the lower top speed predicted in Professor Bairstow's criticism and Mr. Glauert's theory. You would not, moreover, get so many miles per gallon perhaps, but then there is the ability to descend vertically at a safe speed, which means that for private aviation in relatively undeveloped countries there is a very remarkable field for development.

As to military use, I prefer to say nothing. We do not know enough about it yet. The development work going on in this and other countries will throw light upon that.

Mr. HANDLEY PAGE: I think one of the most interesting things about this paper is the extraordinary divergence of opinion among the experts. We who look on as spectators must be interested in the outcome of the arguments relating to this new device. This paper is a second part of a series of papers which I hope we shall have on the autogyro, the first one being the most interesting qualitative account given of the machine by Senor de la Cierva. The one we have heard to-night deals with the theory, and I hope that the next one will deal with the facts. I do not say this in any gibing spirit, but we have only heard to-night an account of the theoretical side of this invention, which would be of infinitely more value if we had some actual measured data such as the actual speeds of rotation, how they compare with the calculated speed, the varying angles of descent and speeds and other such facts that would apply. It appears on the one hand that there are doubts as to whether the facts fit in with the theory or not, and on the other, as to whether the theory fits in with the facts.

When that next paper comes I hope it will be a paper from Senor de la Cierva, but I suppose it will be replied to by a letter from Mr. Glauert, who will be unable to be present. I do hope, however, that then we shall have the facts of the whole thing.

The only machine which one has seen or had particulars has a slow top speed and a slow landing speed. If we raise the top speed to 200 m.p.h., the landing speed apparently also goes up to 60 m.p.h. It seems to me that if a vertical descent is made from any height at this landing speed, the machine will probably descend at a speed of 20 or 30 m.p.h., which is hardly desirable.

Another thing where I think we might improve the knowledge of this subject was if we could have a short résumé of the experimental work carried out on it abroad, say, at Göttingen or elsewhere. I do not know whether Mr. Glauert could supplement his lecture by a résumé of the tests on which he has based his theory.

One thing always strikes me in connection with the autogyro. The lift is obtained from a disc area of diameter equal to that of the blades. If we substitute for this lifting device a circular plane designed to give the same lift at the same speeds, such a machine must necessarily be somewhat inefficient considered as an aeroplane, owing to the relatively high value of the induced resistance, due to its small span compared with the weight carried. I should very much like to hear from Mr. Glauert whether there is any vital difference between the two methods of obtaining lift which invalidates this comparison.

It does seem to me, however, that whatever the theory may indicate, such a machine as the autogyro, descending nearly vertically, must be extraordinarily difficult to control owing to the bad gliding angle and the consequent necessity

to increase the forward speed to reduce the rate of descent. In an ordinary aeroplane the reverse conditions hold good. In addition to this, there is always the difficulty that the controlling organs are, so far as I have seen them proposed, those of an ordinary aeroplane, and these must become of very little use when the forward speed is reduced.

One speaker in the discussion said that the autogyro will be improved if we put on to it a starter or some other means for driving the blades, but in my opinion a whole host of other difficulties would arise. One great advantage of the present windmill is that it goes round by itself, and there is no mechanism to stop it rotating. If you add a starter to drive the autogyro round, the possibility of jamming the machine would have to be thought of. If your motor stopped, up would go your blades with no possible chance of recovery. I do not know what the lecturer has to say to that point.

It seems to me that there are very serious disadvantages on turning the autogyro into a helicopter.

I should like to congratulate the lecturer on the very clear way in which he has dealt with this very complicated question, and only hope that he will at some time be able to add to it the results of a corresponding full scale research work in flight.

Mr. R. K. PIERSON: In 1923 I went out to Spain and saw what I believe were some of the first flights of the autogyro. I know that I witnessed its first forced landing which was entirely successful. On my return we looked into the theory and also made wind tunnel tests, from which our conclusion in regard to the vertical velocity agreed with Mr. Glauert.

In the wind tunnel tests we found that there was a very large scale effect at small angles, and I believe that the results obtained were unduly pessimistic; we carried out tests with rigid blades and also with pivoted blades, the former giving much lower test figures.

I have to thank the author for a very interesting paper and hope that the vertical velocity question will be cleared up.

Mr. MCKINNON WOOD: I fear I am going to quarrel slightly with my elders and betters; first with the Director of Scientific Research, who appeared to speak of the autogyro as a helicopter. Senor de la Cierva has said that it is not a helicopter, and I think he is right. He has replaced the wings of an aeroplane by a windmill. We must give him the credit of producing an entirely new type of flying machine. To the types "ornithopter," "glider and aeroplane," "helicopter," he has added the new type "autogyro."

A way of looking at the autogyro recently occurred to me, which I will put before the Society, because it is perhaps helpful in explaining its characteristics. If we wish to reduce the lowest speed of an aeroplane we increase its area, or use some device for increasing the stalling angle—slot or flap or change of section: generally the area is increased. Senor de la Cierva, instead of adding area, adds speed, by virtue of the rotation of his comparatively small sustaining surfaces. The sustaining elements operate roughly at constant mean lift coefficient and speed. The result is that stalling, in the sense of the breakdown of flow, has been eliminated. The "stalling" to which Mr. Glauert refers is not the more or less sudden change that occurs with the aeroplane, accompanied by danger of loss of control, but a very gradual passage through a maximum of lift coefficient; and the dangers of stalling have been eliminated, while a very high lift has been obtained for the surface used.

So much for the credit side: now for the debit side. An aeroplane flying at top speed carries more area than it needs, because it requires that area to fly at low speeds. In an autogyro the area is much less, the extra speed of the lifting area compensating for this at low speeds. It is not at once obvious that the autogyro may not gain as much at top speed in reduced area as it loses in excess speed, and it is here that I quarrel with the argument advanced by Prof.

Bairstow in the discussion on Senor de la Cierva's paper when he pointed out that the sustaining elements of an autogyro travelled a greater distance than those of an aeroplane when the whole machine travelled from A to B. While the elements of the former certainly travel a greater distance, the profile drag is less. It is not obvious, from this simple argument, that the autogyro may not be as fast as the aeroplane.

Coming now to the case of climbing, when the aeroplane's speed is reduced in order to climb, the profile drag loss falls rapidly—at half-speed it is of the order of one-eighth—whereas in the case of the autogyro this loss changes little between top speed and climb, because the speed of the lifting elements through the air changes little. Mr. Glauert assumes that the induced drag loss is the same for autogyro and aeroplane at the same weight, span and speed—a very reasonable assumption. It follows that the autogyro must be inferior in climb and ceiling. This conclusion is supported by Mr. Glauert's fuller analysis and by model and full scale experiments.

Mr. Glauert finds the autogyro inferior in top speed; but the basis on which autogyro and aeroplane should be compared is perhaps debatable; and, moreover, I think Mr. Glauert will agree that the theory becomes complex and difficult at the finest angles of incidence of the autogyro disc and his prediction of drag at top speed is open to some uncertainty.

In conclusion I would express my humble admiration of Senor de la Cierva's great conception and of the way in which he has carried it out.

Communicated: To Senor de la Cierva belongs the credit of introducing in his "autogyro" a very pretty system of articulated planes in order to equalise the moment of the lift forces throughout the rotation in spite of variation of speed. I believe that more or less this system will be used in any good attempt at constructing a helicopter in the future.

With regard to vertical descent, I keep an open mind, in view of the conflicting evidence, pending further full scale tests; but I think the importance of vertical descent to the ground without flattening out tends to be exaggerated. The proved capabilities of the autogyro, as we have seen it, to glide steeply on to the ground at a low speed—say, at 30° to the horizon in a dead calm—provides nearly all that a vertical descent would provide, and makes a distinct advance on the aeroplane as we know it. Such descents made at Farnborough into a light wind seemed almost vertical to the spectators. Mr. Glauert suggests that the advantages of the autogyro in this respect must decrease with increase of top speed. I am not able to dispute this conclusion, and I am inclined to think that the autogyro will most favourably compare with the aeroplane for machines of moderate performance which are not required for use at great heights.

Mr. Lock: I find it difficult to criticise this paper in view of the fact that ever since the theory first appeared, more than a year ago, I have been attempting to find flaws in it, both by experiment and to a small extent on the theoretical side, so far without success. In fact, all the work that has been done in this interval has tended in the main to support the conclusions of the theory.

There is a point I should like to make in connection with the letter from Senor de la Cierva which has been circulated. When the autogyro was first introduced to this country, Senor de la Cierva based his predictions of high efficiency largely on the results of some Spanish wind tunnel tests of a small model autogyro. Since that time wind tunnel experiments have been made in this country on both small and large models, and although they show considerable scale effect, they do not confirm the high maximum lift over drag of the Spanish experiments. It appears from his letter that Senor de la Cierva now considers that wind tunnel tests on the autogyro are of no value on account of scale effect.

Mr. McKinnon Wood says that the autogyro cannot stall. It seems to me that the autogyro does stall, but at the wrong end, *i.e.*, at high forward speed and not at low speed. At high speeds the blade elements of the receding blade stall, and it is difficult to avoid the conclusion that this must reduce the efficiency. On the full scale machine this effect may be just beginning to be important at the highest flying speed attained, and the efficiency may become very much worn if the present value of the ratio of tip speed to forward speed is much exceeded.

Dr. E. G. RICHARDSON: I was very interested in Mr. Glauert's paper, as I have been doing some experiments myself on a single "flapping wing" rotated at constant speed about a vertical axis in the through draught of a wind channel. Under such conditions the maximum and minimum values of the lift would occur every time the blade lay at 90° to the axis of the channel. I was rather surprised to find, however, that the maximum and minimum inclination of the blade to the shaft or "coning angle" occurred when the blade had nearly reached its upstream and downstream positions respectively, so that there was a lag of nearly 90° (depending on the speed of rotation of the windmill) in taking up equilibrium positions. Actually, of course, the problem is dynamical rather than statical, and the lag observed is probably that common to all forced oscillations, such as this flapping, but I think this lag should be taken into consideration in a theory of the autogyro.

At Göttingen, Seiferth has obtained lift/drag curves for a model autogyro. Such curves as Mr. Glauert has pointed out are very flat-topped; but at very small angles of incidence (about half a degree) Seiferth found that the lift suddenly dropped, and the speed of rotation of the windmill with it, when a critical speed was reached. This shows that the "stall" which may occur at high forward speeds due to the reduction of the angle of incidence, mentioned by Mr. Lock, is one that must be contemplated.

Mr. BRAMSON: I find I have down a mass of questions, and in view of the very pronounced disagreements both as regards theory and practice, one cannot be blamed. There seems to be no agreement even on the pronunciation or spelling of the name of the invention.

One would very much like to know what does happen in a stall in an autogyro. Is it similar to that of an aeroplane? Does stalling mean the stalling of the machine as a whole, or the stalling of the blades? If it is a stalling of the blades, then one can conceive some such terrible catastrophe as Mr. Handley Page suggests in a folding up of the wings.

Another question. Mr. Glauert, in his paper, talked about the minimum speed. Does he mean the horizontal component, or the speed along the path of the machine at the moment?

In these very extraordinary dropping tests that nobody agrees on, was the rate of rotation of the wings considerable, and was it found to agree with what theory would indicate?

Whilst thanking the lecturer for a most admirable paper, I should like to be allowed to record it as my opinion that the autogyro is undoubtedly the most wonderful invention in aeronautics in the last ten years. I think we should not forget that we have in the autogyro, as has been pointed out, a completely new method of keeping afloat in the air. It is bound to have further surprises in store for us.

Major A. R. LOW: He had studied the problem of the "autogyro" under instructions from the Director of Research, who had given him permission to express his (the speaker's) personal opinions. They all recognised the interest and value of the lecturer's work in developing the somewhat lengthy and laborious algebra of the blade element method for such a variety of assumptions.

But he would draw a clear distinction between the elaboration of empirical or semi-empirical expressions, however necessary and useful they might be, and investigation of the underlying physical principles.

Further, it was only fair to remember that Senor de la Cierva had carried the blade element analysis up to the point where he had been able to evolve the existing machine, without which many essential performance data used by the Lecturer would never have been available and had anticipated nearly all the assumptions now made.

Immediately after the test data became available the present speaker had worked out, by a graphical method which much lightened the labour of computation, the reactions on the blades for assumptions as to speed disc incidence, flapping angle, etc., based on information from Senor Cierva, on photographs and on test data, somewhat roughly of course.

He had been astonished to get a positive torque round the whole circle and too large a lift. On assuming smaller effective flow through the disc, that was to say a larger uniform induced downwind, he had been able to get zero torque, together with approximately the lift desired and reasonable balance between opposite blades.

The zero torque was the net sum of a large number of torque elements, some positive round approximately half the circle, the rest negative round the other half circle.

It was this graphical analysis which had made clear to him for the first time the very simple aerodynamical relation between the blade setting and the direction of the resultant force which made autogyration possible, and also the fact that it had nothing to do with the autorotation of a stalled aeroplane in a spin.

Thus the lecturer would see that experimental knowledge of the vanishing of the resultant torque, regarded as the double integral of elementary torques taken along the blade and round the circle, had preceded knowledge of the simpler relation and not the other way round.

The director of Research had given a lucid account of the principle and had added a number of elegant applications in a paper to the British Association (reprinted in *Engineering*, 19th August, 1926, pp. 246-248).

Having in this way realised that the asymmetry of the motion had nothing to do with the autogyration, but on the contrary reduced the range of positive torque, the speaker had gone on to consider what now was seen to be the simplest case, namely, steady vertical descent, calculating the induced velocity as that due to a stable spiral of trailing vortices without increase of diameter as it left the blades.

The induced angular velocity was found to be small and scarcely affected the effective relative angular motion which could therefore be calculated closely (in the actual example within one or two per cent.). But the calculated vertical component of induced velocity was found to be very much greater than the whole observed velocity, so that the assumption of an undisturbed spiral vortex system was in very serious error. He had attempted to investigate the instability of the closely wound spiral vortex, but had found that the problem was at present beyond any available methods of analysis. It seemed clear from experimental evidence that the spiral increases in diameter and very rapidly becomes unstable and diffused.

In horizontal flight the trailing vortices were rapidly carried away and their effect was much smaller, and this was fortunate for the problem was much complicated by the changes of incidence and of velocity in a symmetrical flight. They really knew little or nothing as to the rate at which changes in lift and circulation lagged behind changes in velocity and incidence.

He thought that the best line of progress was to measure the actual motions of the blades and to explore the velocity field round the disc—no easy matter. They might then be able to separate the fundamental physical factors from the composite effects at least to some extent.

To illustrate their present doubts and difficulties, the reports of the full-size tests gave the vertical rate of descent as about 5 m/s., the dropping of a ten-foot model as about twice that figure when reduced to dynamical similarity and the calculations about four times the first figure.

He had not seen how the ten-foot model dropping tests could be in serious error and had been prepared to accept them on the basis that the full-size descent might have been far from vertical, but further full-size tests were reported as "vertical" and again gave one half the model dropping figure. He therefore felt disinclined to commit himself to a conclusion until the full-size tests were either confirmed or explained away, and would leave members of the Society to make up their minds as he could not make up his own on the evidence available.

THE CIERVA AUTOGYRO COMPANY LTD.

Bush House,
Aldwych, London, W.C.2.
January 17th, 1927.

Colonel The Master of Sempill,
The Royal Aeronautical Society,
Sardinia House, Kingsway, W.C.2.

Sir,—I have received your kind letter of the 13th instant in which you are good enough to ask me to take part in Mr. Glauert's lecture on "The Autogyro." Owing to the uncertainty of my being in London on the date arranged and also my difficulty in speaking your language, I have considered it preferable to write this letter, which I have based on the advanced announcement of Mr. Glauert's lecture and on his reports. I should be very grateful if somebody would read this letter after the lecture.

In the first place I must, with respect, record my protest against the manner in which Mr. Glauert has made assertions in an almost axiomatic form, from which the evident conclusion must be drawn that the autogyro is, in effect, useless. Such assertions are based only on very incomplete and uncertain calculations which I am able to state are not at all in agreement with the experimental results.

The autogyro, in spite of its extreme simplicity, is not at all an obvious problem, and any attempt to develop its theory as an extension of the aerofoil theory must perforce be regarded with very great diffidence owing to the fact that, in order to avoid almost insuperable complications in the calculations, it is necessary to attempt to simplify the phenomena and perhaps also to neglect terms which might seem to be of the second order whereas in fact they may be, under certain most interesting conditions, of the first order.

Further, the conditions in which the autogyro blades work are rather different from the uniform simple conditions assumed in the aerofoil theory.

In point of fact this protest against Mr. Glauert's methods themselves and their conclusions should be my only intervention in this discussion, since having been so many years engaged in experimental work I prefer to prove my assertions with facts rather than with theoretical arguments. My experiments have now arrived at a critical stage, which will prove, in a short time, the actual capabilities of the autogyro system, and in these circumstances I cannot see any special reason at the moment to depart from my policy. Further, it seems rather premature, just at this critical time and before anything much is known of the actual

possibilities of the autogyro in the matter of performance, that a lecture should be given disparaging to its assumed performance. I feel sure, however, that it will be of interest to your Society to know certain facts which contradict absolutely Mr. Glauert's results. These facts are :—

(*a*) The lift/drag of a primitive experimental machine with a very unfavourable wing loading and pitch angle was calculated conservatively from official speed tests and found appreciably better than that corresponding to Mr. Glauert's theories.

(*b*) The rate of descent in a practically vertical path from some 500 feet was found in repeated official tests to be some 50 per cent. of that allowed by Mr. Glauert.

(*c*) All Mr. Glauert's considerations and conclusions concerning the lateral tilting of the plane of rotation are entirely different from the practical results, which proves that this phenomenon is much more complex than he allows for, and depends mainly on other facts than the dihedral effect.

I could discuss all matters concerning the optimum pitch angle and several other points, but I shall only draw your attention to the conclusions drawn by Mr. Glauert from the fact that the reaction in an aeroplane lies forward of the normal to the chord, namely, that the aeroplane is always more efficient than the autogyro. The fact quoted above is only true for certain medium angles of incidence, and for the smaller angles the line of argument is inapplicable; it is precisely at such angles that the autogyro will show its best lift/drag. Further, I disagree with his supposition that a price is paid for the elimination of the rolling moment by hinging the blades in that it produces a fore and aft tilt of the plane of rotation, thus introducing additional drag, for thereby at the same time an extra lift is introduced owing to the effective increase in incidence of the whole rotor.

But whatever may be the possibilities of the autogyro reaching the same lift/drag as that of the aeroplane, my own theory and development work lead me to the conclusion that the autogyro will have performance at least as good as, and possibly better than, the aeroplane, since lift/drag is not the sole criterion of performance.

As to the arguments based on wind channel experiments, I can say I am acquainted with many such experiments made in different countries with truly puzzling results differing by hundreds per cent. But the scale effect, important as it is for certain aerofoils, is in fact enormous for the autogyro mainly because of the much greater percentage of frictional losses in the whole drag. Personally, I consider such experiments of little or no use at the present stage of knowledge.

To resume my intervention, I disagree with almost every point contained in Mr. Glauert's developments, which in any case are wrong both in principle and in conclusions, and also in many details. This observation does not involve any personal criticism of such an eminent mathematician, whose mistake is, I believe, that he has tried to treat in too simple and theoretical a manner, a most complicated and novel aerodynamical problem, and that he has considered his conclusions as proved when he might well have waited for the shortly forthcoming tests to tell us the truth.

Up to the present stage my own experiments and theory have been in agreement, and when the moment arrives I will request your Society to do me the honour again of listening to the report of my results together with my theory. I am confident that I shall then be able to remind everybody of the risk of mistake which is necessarily involved in trying to limit from the beginning the possibilities and improvements of any new system when no demonstrated physical facts are available by way of confirmation or otherwise.—I am, Sir, your obedient servant,

(Signed) J. DE LA CIERVA.

Reply to Discussion

Mr. Glauert: It is rather difficult for me to reply to Senor de la Cierva's contribution because on the whole it is simply a statement of disagreement and I am not acquainted with the particular experiments to which he refers. All the experimental evidence which I have seen, both model and full scale, indicates that the lift/drag ratio of an autogyro and the performance of the aircraft is rather less favourable than I should estimate theoretically. I hope, however, that I have not given the impression that the autogyro is "useless." I believe that it is less economical than an aeroplane, but that it has very considerable advantages as regards safety and ease of landing.

Mr. Wimperis and Mr. Handley Page both mentioned the question of power drive to the windmill of an autogyro, but the question evidently arises: When is an autogyro not an autogyro? If the term "autogyro" does not signify free rotation of the blades, what does it signify? Of course, if the power to drive the windmill is available for other reasons, *e.g.*, for starting the rotation, it is tempting to use it in flight also, but my calculations have led me to the conclusion that Senor de la Cierva has acted correctly in using all the available power to drive the tractor airscrew.

Mr. Handley Page also asked for experimental results. Some experiments have recently been made at Göttingen, but the best lift/drag ratio obtained was only 5 or 6 and the maximum lift coefficient was less than 0.4, inferior in both respects to the values given by my theory. It is interesting to note also that the Göttingen experiments showed that the rotating blades were inferior in every respect to a circular disc of the same diameter.

The question of the rate of vertical descent has been raised by several speakers. The rate of descent in the few full scale tests appears to be roughly half that indicated by theory and by all model experiments. Personally, I cannot reconcile this slow rate of descent with the fundamental laws of motion, nor can I believe in so tremendous a scale effect as would be required to increase the drag coefficient of the windmill four times. On the other hand I can see several ways in which the full scale results may be illusory. I think there may be a psychological explanation of the discrepancy. An autogyro descending at 30° through the air into a slight wind would appear to be descending vertically, and it is extremely difficult to determine when an autogyro is really descending vertical through the air. I agree with Mr. Wood that an exaggerated importance has been attached to this question of vertical descent. To be able to descend at 30° to the horizontal with a vertical component of velocity of only 16ft. per second is to achieve effectively a safe descent which is near enough to the vertical for all practical purposes.

Mr. McKinnon Wood and Mr. Bramson raised the question of stalling. I have used the term stalling speed to denote the speed corresponding to the maximum lift coefficient. In an aeroplane this maximum occurs owing to the flow breaking down, but in an autogyro it is due to the increasing backward inclination of the force which is approximately normal to the plane of rotation of the blades. The stalling of the blades, in the sense of the flow breaking down, occurs at small angles of incidence and high speed. In consequence there is a large scale effect in this region and the efficiency of the system breaks down suddenly when this incidence is reached.

Mr. Richardson is surprised to find the maximum upward inclination of the blade in the upward position, and says that this "lag" should be taken into account in the theory. I can assure him that it has not been neglected. It is the very obvious physical result of the fact that the blade tends to have its maximum lift when at right angles to the wind and therefore reaches its maximum upward inclination 90° later.

Mr. Irving raised the question of the forward or backward inclination of the resultant force. The comparison between an autogyro and an aerofoil is complicated by the question of what aerofoil system one ought to consider. The only point I wished to make is that the resultant force is always inclined backwards from the normal in an autogyro, but by choosing an aerofoil of suitable size, set at the same angle of incidence, we can get the same resultant force, but inclined forwards from the normal.

Colonel SEMPILL : I am sorry that we have not had the privilege of hearing any member of the Company which is exploiting this invention beyond receiving a letter from Senor de la Cierva, but in that letter you have noticed that he promises to give us a lecture when his experiments are more advanced. On that occasion I do not think we shall be satisfied, as Mr. Handley Page suggests, in receiving a letter from our lecturer of to-night. We shall insist on his being there to lead the discussion.

I now call upon you to show your cordial appreciation of Mr. Glauert's lecture.

PROCEEDINGS

SEVENTH MEETING, SECOND HALF, 62ND SESSION

The Seventh Meeting of the Sixty-Second Session of the Royal Aeronautical Society was held in the Theatre of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, on Thursday, March 17th, 1927, when Mr. M. A. Giblett, M.Sc., read his paper on "Line-Squalls." Colonel the Master of Sempill, Chairman of the Society, was in the chair.

LINE-SQUALLS*

BY M. A. GIBLETT, M.SC. (LOND.),

SUPERINTENDENT, AIRSHIP METEOROLOGY DIVISION, METEOROLOGICAL OFFICE, AIR MINISTRY.

1. The subject of "Line-squalls" is one which has not been entirely neglected in the proceedings of this Society, but it has not hitherto been treated in any degree of detail. Sir Napier Shaw, in a lecture delivered on January 7th, 1914, on the subject of "Wind Gusts and the Structure of Aeriai Disturbances," briefly cited the line-squall as a phenomenon involving a violent commotion in the atmosphere, illustrating his remarks by sketches and meteorological records relating to a well-marked instance on October 14th, 1912, at Aberdeen. Three years later, on May 2nd, 1917, a lecture was delivered by Mr. C. J. P. Cave, entitled "Some Meteorological Conditions which increase the Danger of Flying," in which the line-squall was again referred to. The need for a warning organisation and the possibility of establishing such machinery received mention. In more recent times the subject was again taken up by Dr. G. C. Simpson in the course of a lecture on "Thunderstorms and Aviation," delivered on November 27th, 1924. But here the matter was treated only incidentally, the line-squall being one of the conditions with which thunderstorms are associated. In this case, charts were reproduced showing the progress of the line-squall of February 8th, 1906, from north-west to south-east across the British Isles, and the classical Aberdeen line-squall of October 14th, 1912, was again referred to, with accompanying sketches of the cloud formation.

Now in the discussions following these papers certain questions have recurred such as :—

To what height do line-squalls extend?
What is their length?
At what speed do they advance relative to the air?
What is their length of life?

Perhaps I am not wrong in assuming that it is because there is a real demand for more complete answers to these and similar questions, than the scope of previous discussions has permitted, that the Council of your Society have done me the honour of inviting me here this evening to deliver this lecture. It shall be my endeavour to present to you as complete a picture as time and present knowledge permit, but I must warn you at the outset that there is still much which the meteorologist himself would learn about the phenomena we are to consider. In addition to dealing with the structure and behaviour of line-squalls, I propose to refer also to their occurrence in various parts of the world, in view

* Read by permission of the Director of the Meteorological Office.

of the present interest in the development of long distance air routes, and to the organisation which exists in this part of the world for providing warnings of line-squalls.

2 *Meaning of "Squall"*

Let us firstly consider briefly the meaning of the word "squall." It is not a word coined by meteorologists but is of ancient origin, probably nautical, and is described in the New English Dictionary as meaning "a sudden and violent gust, a blast or short sharp storm of wind," thus:—1725 De Foe, Voyage round world—"It blew . . . not only by squalls and sudden flaws, but a settled terrible tempest." It was also applicable to other meteorological elements than wind, thus:—1748 Anson's Voy.—"We had frequent squalls of rain and snow." Squalls were of several kinds, thus:—1823 Crabb. Technol. Dict.—"A *black squall* is attended with a dark cloud, in distinction from a *white squall* when there are no clouds, and a *thick squall* accompanied with hail, sleet, etc." A *straight squall* has been spoken of, meaning one in which there is no change of wind direction. Then again we have:—1846 A. Young, Naut. Dict.—"The *arched squall* . . . is usually distinguished by the arched form of the clouds near the horizon." This is merely a perspective effect when looking at the forward edge of a long straight cloud bank.

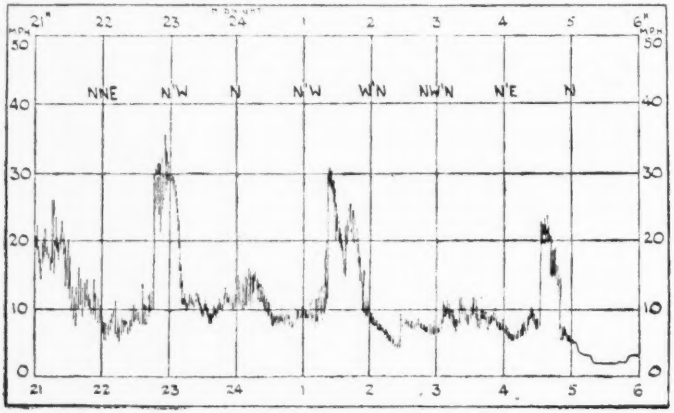


FIG. 1. TYPICAL SQUALLS.
SCILLY. MARCH 3-4, 1908.

The word "gust" seems to have been in use even earlier, and, though no rigid distinction appears to have been maintained, there is a suggestion that this word often implied a rise of wind of shorter duration than was implied by "squall." Some degree of precision was first given to these words as applied to wind when, after their intrusion into the vocabulary of the meteorologist, the pressure-tube anemometer came into being and gave a continuous record of the wind and its minor fluctuations. A portion of such a record of wind speed is shown in Fig. 1, the diagram being a copy by hand of the main features of the original. The minor fluctuations indicated by each excursion of the recording pen received the name "gusts," while increases of wind of longer duration, three examples of which occur in the diagram, were termed "squalls." In the words of Sir Napier Shaw on the occasion already referred to:—"A *squall* is a rapid increase of wind velocity that remains over half a minute at least; it may

include a number of gusts of different force . . . "; while " A *gust* is an increase of wind velocity followed by a lull in less than half a minute; gusts are incidental to all winds."

3 Meaning of " Line-Squall "

Investigations have shown that squalls may occur simultaneously along a line sometimes hundreds of miles long, advancing across the country, and to such phenomena the word " line-squall," taken in its literal sense, is to be applied. However, the incidence of such a squall at a ground station is marked by characteristic manifestations of the other meteorological elements, embracing, according to circumstances, some or all of the following :—

A sudden or rapid change of wind direction.
Heavy rain (or hail or snow).
Thunder and lightning.
A sudden or rapid fall of temperature.
A sudden or rapid rise of relative humidity.
A very rapid rise of barometric pressure during the passage.

I will not elaborate the description here as I shall return to it later, but I will now merely point out that the term " line-squall " is normally applied in the broader sense to the ensemble of occurrences. Indeed, as we shall see, in some cases all these characteristics may be present without the wind speed record showing features strictly within the definition of a squall given in the last paragraph, and yet we must admit such cases into the class of phenomena we are to consider, for we are not merely interested in the wind speed at the surface. The question then arises as to what shall be the basis of the treatment of the subject.

4 Basis of Treatment

Physically, the basic characteristic of the phenomena under review is the rapid fall of temperature. This fall of temperature is due to the arrival at that instant of a distinct colder mass of air replacing the previously existing warmer current, and the " line-squall " is the physical result of this action. Accordingly, the basis of all that follows will be the consideration of events where relatively cold air masses impinge on relatively warmer ones. This will allow a satisfactorily broad treatment and will also bring into prominence the element temperature, which, at least from the point of view of airships, whether moored or in flight, is hardly second in importance to wind.

5 Association with Depressions of Temperature Zones

(a) Juxtaposition of relatively cold and warm air. The " Polar Front."

In the temperate regions the juxtaposition of relatively cold and warm air masses along a line of considerable length is found principally in association with the travelling low pressure systems or depressions of those latitudes; indeed, it is a fundamental feature of their structure. Fig. 2 shows a typical distribution of barometric pressure over Europe and the N.E. Atlantic Ocean, during a disturbed period. It consists of a system of three depressions situated between anticyclones over the Mediterranean area, and over the area south-west of Greenland. Analysis of this situation on modern lines, taking other elements than pressure into account, would reveal a structure the most important feature of which is shown in Fig. 3. Here the stippled area of the chart is that covered at the moment by air of direct or rather recent polar origin, while the remainder of the chart is an area covered by relatively warmer air of recent tropical or sub-tropical origin. Arrows have been added to indicate the wind direction at about 1,500 feet at the time of the chart, the longer arrows indicating the stronger

winds. It will be seen that the dividing line along which the two air masses are in close contact is sinuous, and that it is intimately connected with the depressions, forming a link between them which is not in any way apparent when Fig. 2 alone is considered. It is this line which has received the name "*Polar Front*" on the analogy of a battle-front, because the warm and cold air masses are in a state of conflict along it, the manifestation of this being the barometric depressions and associated air motion.

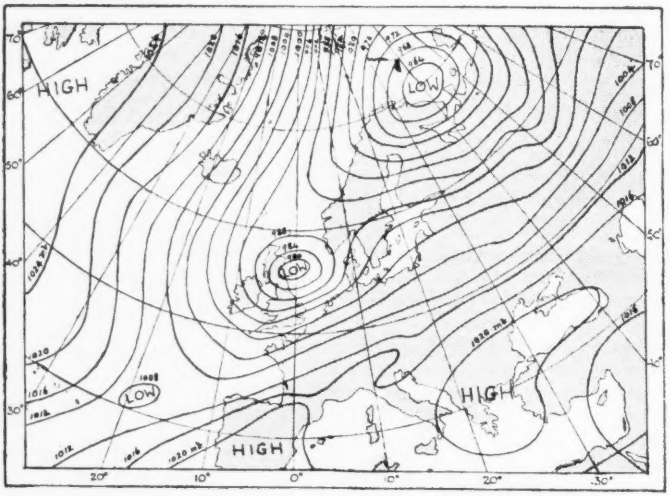


FIG. 2

Typical distribution of barometric pressure over N.W. Europe during disturbed period.

(*b*) *Sub-division of the Polar Front. "Cold Fronts."*

It will be noticed that in Fig. 3 the "Polar Front" is divided up into segments according to an accompanying key. Considering the middle of the three depressions, it will be seen to have a sector of warm air extending to its centre. There is a law that the centre moves in a direction parallel to the isobars of this warm sector, as shown in the figure by an arrow. During this displacement the forward boundary of the warm sector moves into the space at present occupied by cold air; in other words, along this segment of the "Polar Front" warm air is replacing cold, and the segment is called a "warm front." On the contrary, along the segment bounding the warm sector in the rear, cold air replaces warm, and this segment is called a "cold front."

The air of the warm sector, in addition to replacing the cold air at the ground along the warm front, actually gains on it and rises over it. The cold air which replaces the warm at the ground along the cold front, also gains on it, and undercuts it. The result is that as time goes on the cold front gains on the warm front and ultimately overtakes it, the warm sector disappearing. The combined cold and warm front is called an "occlusion," and an example is seen in the northernmost depression of Fig. 3. The cold air in the rear of the occlusion is not necessarily at the same temperature as that in front, having had a different history; it is more frequently colder, in which case the occlusion retains some characteristics of the cold front, for we still have cold air replacing relatively warmer air. The stage of occlusion is one of the later phases in the life history

of depressions, and it has been reached in by far the greater number of depressions in the vicinity of the British Isles. The southern depression of Fig. 3 has only recently formed, and its warm sector is as yet only a small wave in the " Polar Front."

In addition to the segments of the " Polar Front " already described, there are portions joining the cold front of one depression to the warm front of the next. These portions are temporarily stationary, neither warm nor cold air gaining along them. Further, " secondary cold fronts " may occur in the body of the polar air, as illustrated by the example attached to the northern depression in Fig. 3. Here the polar air to the east is being replaced by yet colder polar air of somewhat different recent history.

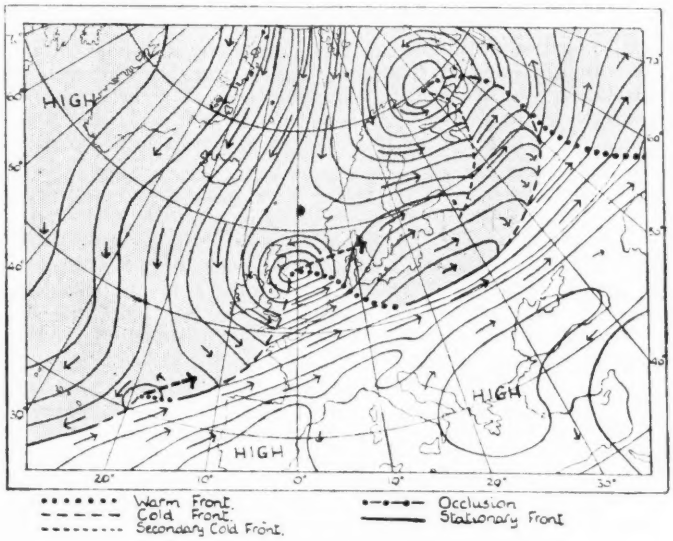


FIG. 3.

Illustrating the " Polar Front."

(Bibliography, Item 1.)

The portions of the " Polar Front " in which we are primarily interested, as being those where line-squall phenomena manifest themselves, are the cold fronts, or segments where the polar air is gaining ground. Similar phenomena may be exhibited along occlusions and secondary cold fronts, but warm fronts are of a totally different character, and their detailed consideration is outside the scope of this account. Cold fronts have also received the name " squall-line," and, in America, " wind-shift-line." What is often called the " trough " of a barometric depression also coincides with the cold front.

Perhaps the most logical view as regards line-squalls is to regard all cold fronts as line-squalls in the broader sense of paragraph 3, but to realise that the associated phenomena may be present with very different intensities in different cases. In what follows, when the word " front " is used without qualification a cold front (or secondary cold front or occlusion) will be implied, but not a warm front.

(c) *Motion of line-squalls; direction; speed; relation to barometric depression.*

We are now in a position to answer certain definite questions about line-squalls. In Fig. 4, the "Polar Front" of Fig. 3 is again reproduced, marked *A, B, C, D . . .* Its position after the lapse of, say, six hours is represented also and marked *A'*, *B'*, *C'*, *D'* . . ., the depression centred at *C* having reached *C'*, that at *F* having reached *F'*, and that at *K* having moved very little to *K'*, slow movement being a characteristic of a depression when the occluded stage has been reached.

Let us first dispose of the idea, once prevalent, that line-squalls radiate from the centres of depressions like the spokes of a wheel. This is certainly approximately true of the cold front in a relatively young depression, such as that centred at *F*, but the cold front *HJ* does not bear such a relation to the occluded depression centred at *K*. Even if notice be taken of the occlusion *JK*, the whole, *HJK*, would form a very crooked spoke of a wheel with axle at *K*.

Is the rate of advance of a line-squall uniform along its whole length? Very definitely no. Remembering that in measuring the rate of movement of a line we must consider the displacement of each section at right angles to itself, Fig. 4 shows that in the case of the depression *F*, the cold front near *F* has

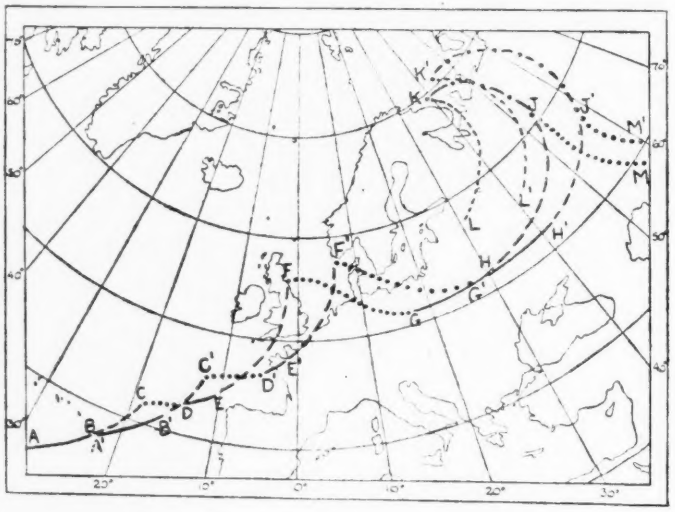


FIG 4

Illustrating the Displacement of the "Polar Front."

(Bibliography, Item 1.)

advanced almost across the North Sea in six hours, about 50 m.p.h., whereas the portion near Brest, having moved very little to *D'E'*, is then temporarily stationary prior to receding as the warm front *C'D'* of the next depression. A rate of advance greater than 60 m.p.h. may occur but is not common; rates of 30 m.p.h. or more are quite common.

Is there any relation between the rate of advance of a line-squall and that of the depression with which it is associated? There is no simple relation. In the case just considered the portion of the cold front near the centre *F* was advancing with approximately the same speed as the centre, as is seen from Fig. 4. But,

though the depression at K is moving only slowly, the cold front at J is still moving rapidly, and this might continue for some time, even though the depression came to rest. There is, however, one simple relationship of practical value when using weather charts, and that is, that in active systems the rate of advance of any section of a cold front is approximately equal to the component perpendicular to the front of the gradient wind in the polar air in its rear (the gradient wind being the theoretical wind at 1,500 feet as readily measured from the isobars on the chart).

What is the normal direction of motion of line-squalls? Normally, from somewhere between N.W. and S.W., but sometimes they move N. to S. or S. to N. There is very rarely a component from the east in the motion. In Fig. 4 alone, examples of portions of cold fronts or occlusions moving within a wide range of directions may be found.

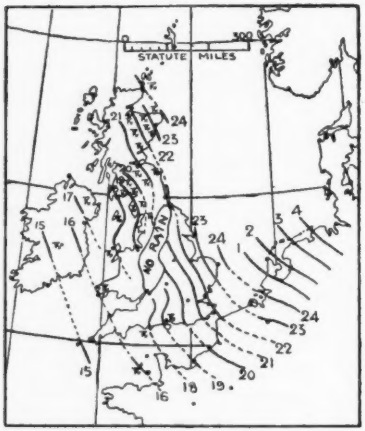
(*d*) *Frequency of occurrence of line-squalls; horizontal length; length of life.*

Since there are cold fronts associated with all active depressions of temperate latitudes the frequency of line-squalls, including all degrees of intensity, is high, but for every severe one there are many of only moderate or slight intensity. Since periods of cyclonic activity occur in spells, separated by spells of settled conditions, line-squalls may recur at any place at short intervals during some periods, and then there may be a period of even weeks free from all such phenomena.

The horizontal length of a line-squall in a characteristic case is well represented by those of the cold fronts in Fig. 4, *i.e.*, anything up to a thousand miles. We have already seen that there is a considerable variation of speed of advance along the front, and we shall later see that the intensity of the associated phenomena usually likewise varies along it.

The length of life of a line-squall is often at least twenty-four hours, but in this connection it is necessary to consider its transition. The length of life may be very different for various portions of the same front. In Fig. 4 the northern portion of the cold front EF will ultimately overhaul the warm front FG and form an occlusion. It may be many hours before this is achieved, and even afterwards the occlusion may have the character of a cold front and persist for a further considerable period before dying out. The southern portion of EF is, on the contrary, slowing down, shortly to become stationary at $D'E'$ and then to become in turn a portion of the warm front $C'D'$ of the next depression. The length of life of the " Polar Front " of Fig. 4, considered as a whole, is much longer than the period during which any one portion of it retains a particular character. It may persist for days or even weeks, undergoing many changes of form, as old depressions die and new ones form in association with it, until ultimately the polar air has spread over the whole area at present occupied by the warm air, or until the polar air has become warmed to such an extent that the contrast of temperature disappears. This marks the end of that particular spell of disturbed weather.

The tracing of the fronts of all types on the weather charts is now a matter of everyday practice with many forecasters, so that there are many examples available of complete fronts on successive charts. However, I have thought it of some interest to reproduce here some of the historical examples of the tracing of the progress of cold fronts. Fig. 5 shows three cases, approaching from the S.W., W. and N.W. respectively, the positions being shown at hourly intervals. Fig. 6 shows the progress of a cold wave across the whole of Europe and Asia in thirteen days. The lines in this diagram are not to be taken as successive positions of the cold front of any single depression, but as giving a generalised picture of the progress of the polar air during a period of cyclonic activity. The diagram implies, however, the persistence of the polar front and its travel during the period mentioned, and so is of considerable interest in the present connection.



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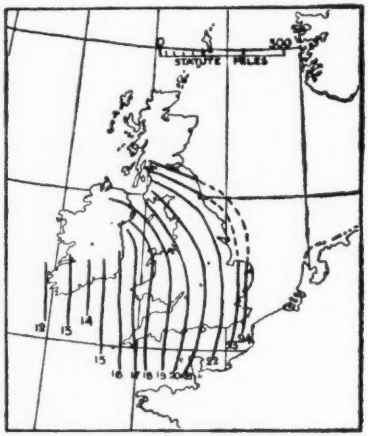
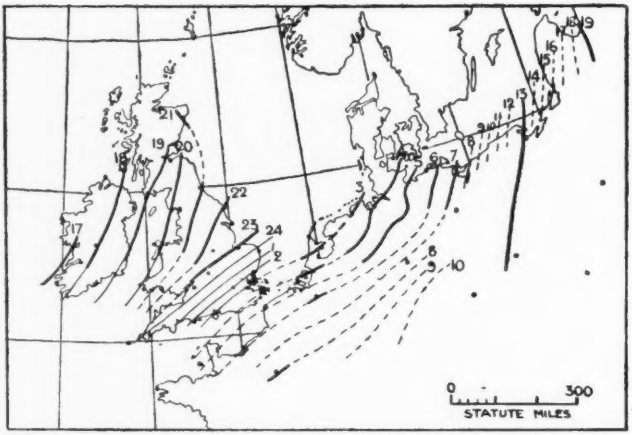


AUGUST 31, 1908.



FEBRUARY 19-20, 1907.

FIG. 5. CHARTS SHOWING ADVANCE OF LINE-SQUALLS ON THREE OCCASIONS. THE LINES SHOW SUCCESSIVE POSITIONS OF THE SQUALL FRONT AT INTERVALS OF ONE HOUR IN EACH CASE.

(Bibliography, Item 2.)

(*e*) *General weather characteristics.*

In Fig. 7 the polar front of Fig. 3 is again shown, while the stippled area represents, necessarily in a somewhat idealised way, the associated rain area. Any rain falling elsewhere would be purely local. The continuous line outside

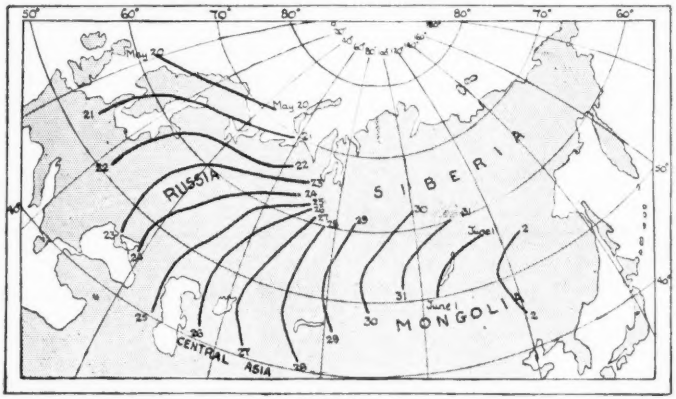


FIG. 6.

Spreading of a Cold Wave during the period May 20 to June 2, 1899.
(after H. v. Ficker).

(*Bibliography, Item* 3.)

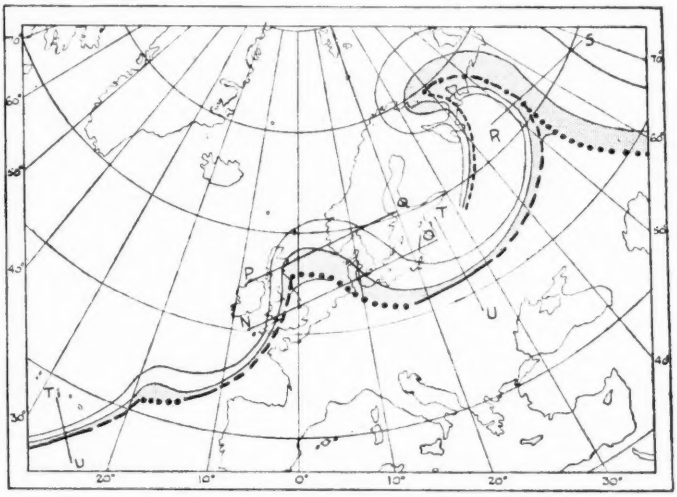


FIG. 7.

Illustrating the association of Rain and Cloud with the "Polar Front."

(*Bibliography, Item* 1.)

the rain area represents the outer edge of the cloud system responsible for the rain. Fig. 8 makes the matter clearer by showing vertical sections along the lines *PQ*, *RS*, etc., of Fig. 7, and gives a generalised view of conditions in

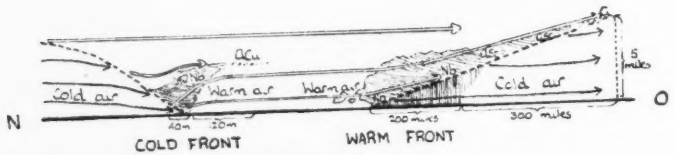


Fig 8a Section along N-O of Fig 7

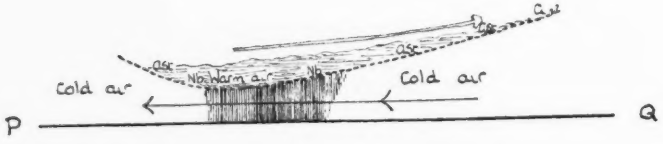
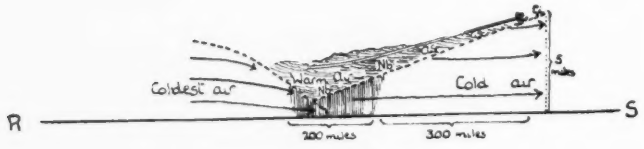


Fig 8b Section along P-Q of Fig. 7



OCCLUSION CASE I.

Fig 8c Section along R-S of Fig. 7.

OCCLUSION CASE II

Fig 8d Section along R-S of Fig 7.

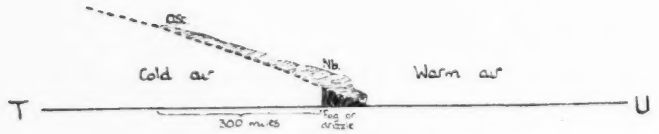


Fig 8e Section along T-U of Fig 7.

STATIONARY FRONT

FIG. 8.

(*Bibliography, Item* 1.)

the upper air. The diagram read in conjunction with Fig. 7 is self-explanatory and a lengthy description is unnecessary. I will merely call attention to the very small angle, much enlarged in the figure, which the sloping boundary between warm and cold air makes with the ground. The portions of the diagram to which interest attaches in the present connection are the cold front of Fig. 8A and the first type of occlusion, Fig. 8C, for those are where the line-squall phenomena occur. The vertical shading represents falling rain. Only the main cloud masses are shown. Broken cloud, scud and thin cloud sheets may also occur both in the warm and the cold air.

(*f*) *Events at a ground station during passage of cold front.*

These are shown for a typical case in Fig. 9, the time of incidence of the cold front being in this case about 13h. The barometric pressure which has been falling steadily shows a rapid rise at the time of incidence, followed by a more gradual rise. The magnitude of the rapid rise is often several millibars in a few minutes. The wind speed shows a sudden increase of short duration followed by a decline to a value less than that before the squall. This is typical, but important modifications may sometimes occur and these will be treated in more detail later. At the time of the squall the wind direction shows a rapid change from south to north-west. This change is often complete in less than a minute, but, though always in the same sense in the northern hemisphere, is often through a much smaller angle. It is, however, sometimes through a larger angle, even amounting to a complete reversal of direction. The temperature shows a very rapid fall. A fall of 10°F. in a few minutes is not uncommon. Some outstanding examples are quoted in a later paragraph dealing with the Southern Hemisphere. The relative humidity shows a sudden rise, but the actual vapour content in the polar air is often less than in the warm air, especially in the British Isles. The characteristic rainfall is an intense shower (sometimes of hail) at the time of incidence of the squall, often accompanied by thunder, and followed by a short period of less heavy rain, often only half an hour. (The rainfall curve in Fig. 9 is such that the height of any point above the base line represents the total fall up to that time, so that when no rain is falling the curve is horizontal.) A secondary squall is shown in the diagram at about 14.30. Reference to Fig. 8A shows that although much of the rain falls through the forward part of the cold wedge, the moisture providing the cloud and rain is actually that of the warm air which is lifted up by the cold wedge. In the British Isles, the warm air is usually moist, but in some parts of the world it is often very dry, and a cold front may frequently pass without rain, and sometimes it may even be a " white squall " without cloud.

(*g*) *Events in the upper air during passage of cold front.*

In the upper air the passage is marked by dense cloud masses and violent vertical atmospheric currents which will receive special treatment later. Reference to Fig. 8A shows that in consequence of the backward slope of the boundary between warm and cold air (the whole system being supposed moving from left to right) the arrival of the cold air, and with it the shift of wind, is delayed the more the higher the level considered. The first thousand feet or so are, however, excepted from this statement for reasons to be explained. The total fall of temperature at, say, 10,000 feet is often much greater than at the surface. Soundings by aeroplane in the British Isles, before and after the passage of cold fronts, have shown falls of 20°F., when those at the surface have only been a few degrees. The precise rate of fall and rapidity of wind shift at the higher levels have not been directly measured, but they probably do not often take place in such a very short time as at the surface.

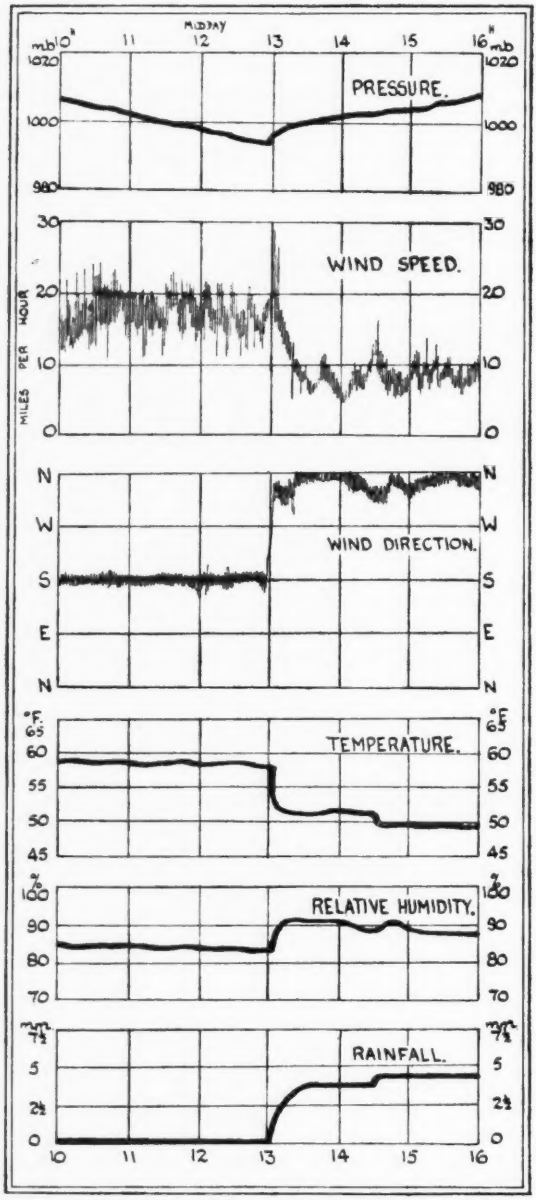


FIG. 9. CHANGES DURING PASSAGE OF A TYPICAL COLD FRONT

(*h*) *Geographical Considerations.*

The cold fronts associated with the depressions of the Temperate Zone may penetrate into quite low latitudes. Violent line-squalls occur from this cause, even in the vicinity of latitudes 30° N. or S., and the polar air may occasionally reach even into the Tropics in sufficient depth and with sufficiently low temperature to cause such effects. Over the central plains of the United States, line-squalls of great intensity are experienced. The warm air in front is drawn from the Gulf of Mexico, and so may be very humid and give rise to heavy precipitation and thunderstorms along the squall fronts where the wind changes to north-west. The Mediterranean often experiences severe line-squalls, especially in winter, with the penetration of cold air direct from higher latitudes. This cold air pouring through the gaps in the mountain chains of Southern Europe forms the Mistral of the South French coast and the Bora of the Adriatic. Secondary cold fronts are also frequent in these polar currents over the Mediterranean, often being due to the meeting of two branches of the same initial current, such as the Mistral and Bora. On the southern shores of the Mediterranean, cold fronts are frequently rainless, for, as we have seen, the moisture for the rain is provided by the warm current in front, and in the area mentioned this is often drawn direct from the Sahara and is exceedingly dry. The cold weather storms of the Persian Gulf and N.W. India are depressions associated with the penetration of cold air from the north, and line-squall phenomena may be manifested in them.

In the Southern Hemisphere, cold fronts occur in association with the eastward moving depressions of the Roaring Forties. Here again the penetration of polar currents into quite low latitudes may cause severe line-squalls there. The Southerly Burster of summer at Sydney, Australia, is an example. Fig. 10

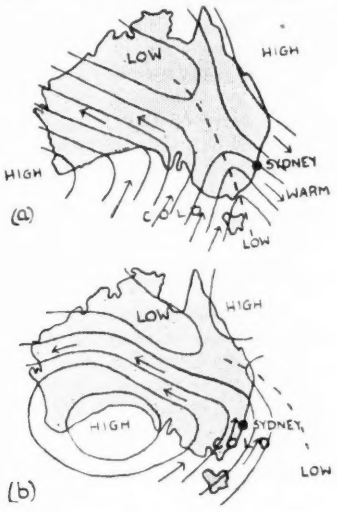


FIG 10. SOUTHERLY BURSTER

(a) APPROACHING SYDNEY

(b) AFTER ARRIVAL

(*Bibliography, Item* 4.)

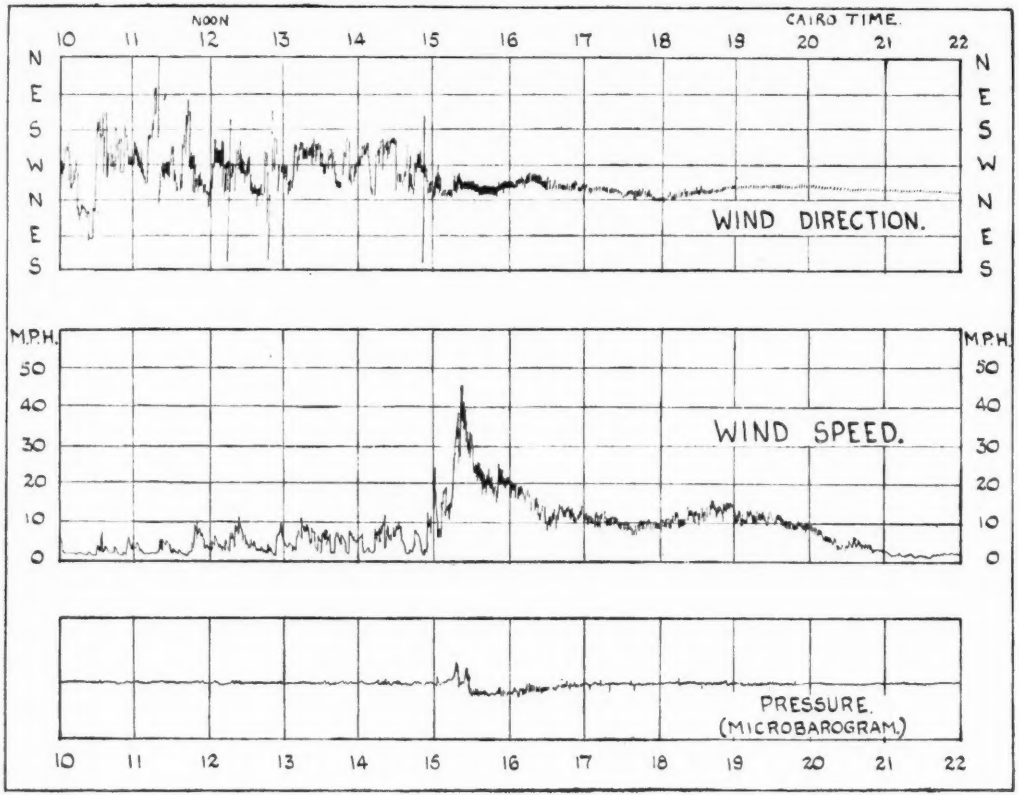
shows a typical weather chart of such an occurrence. Remembering that in the Southern Hemisphere the wind blows clockwise in relation to barometric depressions, we see from Fig. 10A that the typical change during a cold front is from a north-west to a south-west wind. The north-west wind at Sydney may rise to a very high temperature over the interior, so that the contrast of temperature with the advancing cold current may be very considerable. The north-west wind is often very dry, in which case the squall may pass without rain. The following is quoted from a description by the Commonwealth Meteorologist: "The burster is preceded by a period of high temperature varying from three hours to three or more days, accompanied in the early part of summer or towards its close by wind from the west or north-west, and in midsummer months generally from the north-east. As the hour of the outbreak approaches, there begin to accumulate in the south, ball-shaped cirro-cumulus clouds, and frequently, if electric disturbances are to accompany the squalls, heavy cumulus thunder-clouds rise gradually in the south-west. An hour or so before the squall, a heavy cumulus roll appears low down on the southern horizon. . . . As it approaches, careful observation shows a light (cloud) fringe rising from underneath it in front, falling over the top, and trailing behind the advancing cloud. The wind drops suddenly and a profound calm prevails for a short time. Clouds of dust arise to the south . . . the wind-vane flies round to the south, and in a few moments it is blowing with the force of a gale." The total fall of temperature, not all of it sudden, has amounted to 37°F. The average total fall is 18°F., but on December 30th, 1891, the temperature fell this amount in the first five minutes.

Line-squalls of similar character are experienced over the Union of South Africa, Durban being, for example, situated in a similar way to Sydney. A fall of temperature of 18°F. in ten minutes has been recorded at Durban. The Pampero of the Argentine is another example of a line-squall. These occur mainly from July to September. Another region which has been the subject of investigation is the ocean to southward of the Cape of Good Hope, where the line-squalls associated with intense depressions are not infrequently accompanied by thunderstorms.

There are, indeed, few parts of the Temperate Zone not subject at some season to the cold fronts associated with the barometric depressions of that zone. However, the local modifications of these fronts are often considerable, according to the distribution of land and sea in their effect on temperature and humidity. But they can be understood and even anticipated by a proper appreciation of the physical processes involved.

6 *Occurrence of Line-Squalls in the Tropics*

In the foregoing, we have seen that the line-squalls of the Temperate Zones occur along the boundary between extensive warm and cold air masses of considerable depth brought together from low and high latitudes respectively and, further, that the penetration of the cold air masses may carry these effects into quite low latitudes, even into the Tropics. But there are two other ways in which relatively warm and cold air masses of sufficient extent may come together and produce line-squall phenomena, if not along fronts as long as those of the Temperate Zones, yet along fronts of considerable length. The first way is concerned with the sea-breeze in coastal districts. Given certain favourable general conditions, the cool sea breeze does not arrive inland gradually but suddenly, as a cold front, and its arrival may even be accompanied by thunderstorms. This effect may also occur in a marked way in the lower latitudes of the Temperate Zones, but in higher latitudes it is less and less evident. The necessary general conditions are realised in Lower Egypt, and records from self-registering instruments at Abu-Sueir near Ismailia show that, during the hot part of the year, a cold front arrives practically every afternoon. It is usually a very slight affair, and in view of the extreme dryness of the air is usually a "white-squall." It is how-



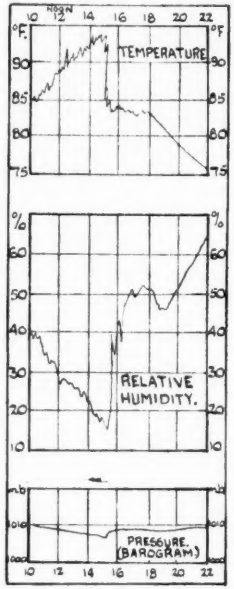


FIG. 11. ABU SUEIR, LOWER EGYPT. (LAT. 30°35'N. LONG. 32°9'E.)
4TH JUNE 1924.

ever sometimes marked, and a very interesting extreme case is shown by the records reproduced in Fig. 11. Cloud occurred with this front, but no measurable rain. An intense dust storm associated with it gave warning of its approach.

The other way is the reverse case when air chilled by radiation at night on high land near the sea flows down and impinges on the warm air still lying over the sea. In the Tropics, the contrast of temperature between the two air masses may be considerable, and in the case of a long mountain chain the resulting squalls may occur along a sufficiently long front to be regarded as line-squalls. The "Sumatras" of the Malacca Straits, which always occur at night, are probably of this character.

The squally character of the "Doldrums" is well known, but whether the squalls there occur frequently along a sufficiently extensive front for them to be regarded as line-squalls needs investigation.

7 *Detailed Structure of Line-Squall*

We will now consider in much more detail conditions a few miles on either side of the line-squall, or forward edge of the cold air in the cold front of Fig. 8a. The horizontal distance considered is only just distinguishable on the scale of that diagram. Owing to the difficulty of observing, no complete survey of any one case at all heights has ever been made, but there are many fragmentary observations available of various phases of different cases. Piecing these together and combining with them personal observations and certain theoretical considerations, I have arrived at a picture of the essential features in the immediate neighbourhood of the line-squall and this is shown in Fig. 12. In this diagram the horizontal and vertical scale is the same, so that a correct idea of the proportions is at once given. The stippled area is a section through the tip of the cold wedge which is supposed advancing to the right. Owing to surface friction the cold air is found farther advanced some distance above the surface than at the ground itself, and the upper limit of the cold air, AB, instead of continuing on until it cuts the ground, is doubled back and meets it at the point C. This point is to be considered as marking the cold front at the ground. The rate of advance of this point to the right in the diagram, or in other words the speed of the cold air at C in this direction, is the rate of advance of the front.

The moment when the barometer normally commences to rise at a ground station is when the point B comes overhead, and as the vertical thickness of the denser cold air above the station increases so the barometer continues to rise rapidly. In a typical case, the passage of the whole portion of the cold wedge shown in this diagram would only be a matter of ten minutes or so. Beyond the left of the diagram the upper boundary of the cold air slopes at a smaller angle still and the rise of pressure consequently proceeds less rapidly. Viewed in another way, the first result stated may be expressed by saying that there is a strong pressure gradient from left to right at the ground along the section so marked in the diagram.

Now the various arrows indicate the main features of the air motion in the plane of the diagram, *relative* to the point C, *i.e.*, as they would appear to an observer travelling along with C. (The velocity of C is then to be added at all points to obtain the actual motion.) The arrow at D means that the air there is being overtaken by the cold wedge. When this air arrives at E, it immediately comes under the influence of the strong pressure gradient and its relative motion is checked or even reversed. It is therefore on the passage of this point that the first sudden change of wind takes place at a ground station. The squall as measured on an anemogram may be said to have commenced. It continues until a little after the passage of C, when a decrease of wind takes place. The arrow at H indicates that the air there is losing on the front C.

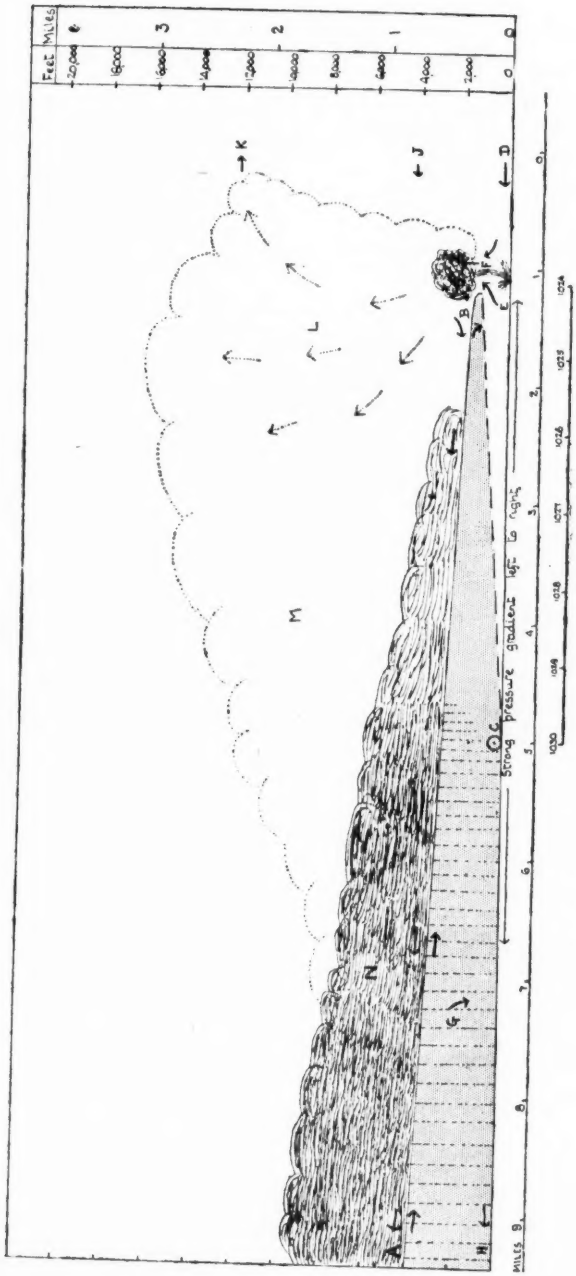


FIG 12. DETAILED STRUCTURE OF LINE-SQUALL.

As regards vertical motion, the strong horizontal convergence between *D* and *E* necessitates a strong upward current at *F*. If there is sufficient water vapour present, cloud will form here and, owing to the tendency of the cold air at *B* to fall, a rolling motion as indicated may be imparted to this cloud, which is the characteristic long roll cloud of a line-squall seen in cross-section. Two remarkable photographs of such clouds seen in the Mediterranean are shown in Figs. 13 and 14. In many line-squalls this cloud is obscured by larger cloud masses and so is often not clearly seen.

On the other hand, the divergence between *C* and *H* necessitates a downward current at *G*. This is in general quite gentle, being spread over a wide area and not concentrated like the upward current at *F*. However, if heavy rain is falling at *G* its drag may increase the downward current to a not inconsiderable amount.

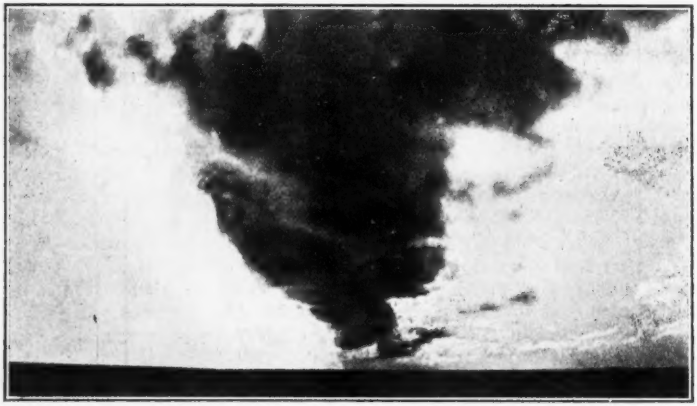


FIG. 13.

Photograph of Line-Squall Cloud taken from ss. "Arracan," Captain W. Y. Hamilton, Port Said to Marseilles, by Mr. A. L. Rowlands, Second Officer, at noon, on May 10th, 1922, in Latitude 35° 46′ N., Longitude 21° 17′ E. (*Bibliography, Item* 6.)

The warm air, having risen over the front edge of the cold wedge, is further lifted above the upward sloping boundary *AB* and, if moist enough, a cloud sheet will form as at *N* and from this rain may fall through the cold air beneath. The whole system as so far described represents the phase of development of the Aberdeen line-squall of October 14th, 1912, of which a detailed description, accompanied by cloud sketches, has been given by Mr. G. A. Clarke in his book on "Clouds." The sketches were reproduced in Dr. Simpson's lecture, while from Mr. Clarke's description of the sequence of events I have received confirmation of the structure indicated in Fig. 12. Assuming a rate of advance in that case of 40 m.p.h., which was undoubtedly near the truth, the horizontal scale of miles shown in the diagram then applies, and the second scale shows the time at which the various parts of the system passed the observer. At 10.24 the roll cloud was commencing to form along a line passing almost overhead, and the wind veered suddenly from S.S.W. to W.N.W., the latter being at right angles to the front. It was not until six minutes later that the final burst of wind and fall of temperature at *C* arrived.

The cold air between *B* and *C*, lying over the warm air between *E* and *C* is a very unstable condition and some mixing is to be expected. I have observed there a most amazing state of turbulence revealed by the motion of cloud fragments, just after the passage of the line-squall cloud *F*.

I have been led, in studying the structure of these squalls, to give the under boundary *BC* of the cold wedge an angle of slope as small as that shown. I have now been informed by Mr. N. K. Johnson, of Porton, that special temperature measurements he has made up to 300 ft. on a wireless mast, confirm this, and I am very much indebted to him for allowing me to foreshadow the results he is about to publish.

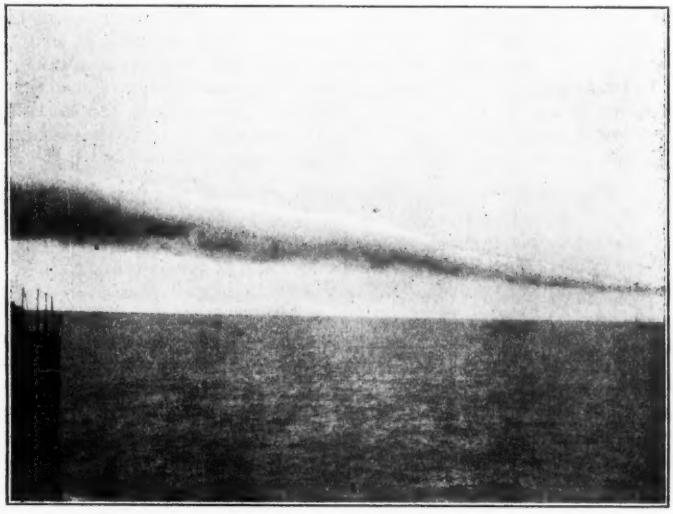


FIG. 14.

Photograph of Line-Squall Cloud taken from ss. "Nore," Captain R. M. M. Collyer; Observer, Mr. L. J. Edwards; London to Port Said, on May 4th, 1921, at 9.30 a.m., in Latitude 32° 33′ N., Longitude 28° 28′ E. (*Bibliography, Item* 6.)

8 *Conditions for Thunderstorms to Accompany Line-Squalls*

The advance of the cold wedge having caused the initial rapid rise of the warm air at *F* and the formation of the roll cloud, further ascent may not be limited to the gradual ascent up the surface *AB* and formation of the cloud sheet *N*. If the warm air in the layer *JK* is unstable with respect to saturated air, *i.e.*, if the temperature there falls with height at a rate greater than a certain value admitting of quantitative expression, then the warm air at *F*, once started rising vertically, will continue to do so under its own buoyancy, and a towering cumulus cloud will form in the space *ML*, with the possibility of thunder, lightning and heavy rain or hail. The part played in this process by the cold wedge is merely that of pulling the trigger. The humidity conditions and the stability of the warm air may vary along the same front so that thunderstorms may occur in some places and not in others.

9 *Vertical Extent of Line-Squalls and Their Rate of Advance Relative to the Air*

We are now in a position to answer the question as to the height to which line-squalls extend. The violent motions peculiar to the line-squall are limited to the first few thousand feet, but above this the usual intense vertical currents of thunderstorm clouds, already described by Dr. Simpson, may occur up to 15,000 or 20,000 feet.

Since Dr. Simpson's lecture two further pieces of information have become available concerning the magnitude of the vertical atmospheric currents within thunder clouds. The first was a direct determination of a vertical current of the order of 2,000 feet per minute extending through a vertical distance of 10,000 feet, in a thunder cloud in the United States. These values were obtained from the traces of recording instruments carried on a kite which broke away during the storm and was taken up in this violent current. The second was in the form of a photograph of very large hailstones which fell during a thunderstorm at Dallas, Texas, on May 8th, 1926. The photograph is reproduced in Fig. 26. The estimated diameter of these stones is $2\frac{1}{2}$ inches, and the vertical current required to hold such stones up in the atmosphere during the process of their formation may be deduced from the following table which is due to Dr. Simpson.

END VELOCITIES OF HAILSTONES AT 4 KM. (13,000 FEET).

Diameter. Inches.	Rate of Fall relative to the air. Miles per hour.
$\frac{1}{2}$	36
1	51
$1\frac{1}{2}$	63
2	72
3	90

It will be seen that a diameter of $2\frac{1}{2}$ inches corresponds to a vertical current of about 80 miles per hour or about 7,000 feet per minute.

As regards the motion of the squall relative to the air in front, we have already seen in considering Fig. 12 that the warm air at *D*, *i.e.*, at the surface, is being overtaken by the squall, so that, for example, a free balloon would be drawn into it. It is probable that in the majority of cases this effect decreases with increasing height, until at *K*, for example, the warm air is slowly leaving the cold behind. The rate at which the squall gains on the warm air at *D* may be very small in some cases, but it may range in others to considerable values, 40 m.p.h. or even more.

10 *Varieties of Wind Changes During Line-Squalls*

In Fig. 12, only the component of the wind in the plane of the diagram, which is at right angles to the front, is considered. There may also be, and in general are, components parallel to the front. Time does not allow the detailed discussion of the various possible types of anemogram associated with line-squalls, but a diagram, Fig. 15, is given in illustration. The first is the normal type, the squall occurring in this case just before 15h. The second shows a case where the wind before the squall is so strong as to mask it entirely, the wind commencing to decline suddenly, without a temporary rise, just before 19h. Although in such a case no squall is shown in the strict sense, all the other line-squall phenomena may be present. (The true squall shown later in the same anemogram was a secondary squall in the polar air.) The third shows a rarer type with cold fronts, viz., one in which the wind rises suddenly and then maintains its level. The next illustrates the fact that even when the surface wind is almost calm, both before and after, yet the squall may be severe. The last is an outstanding case of an isolated gust of 80 m.p.h. during a line-squall.

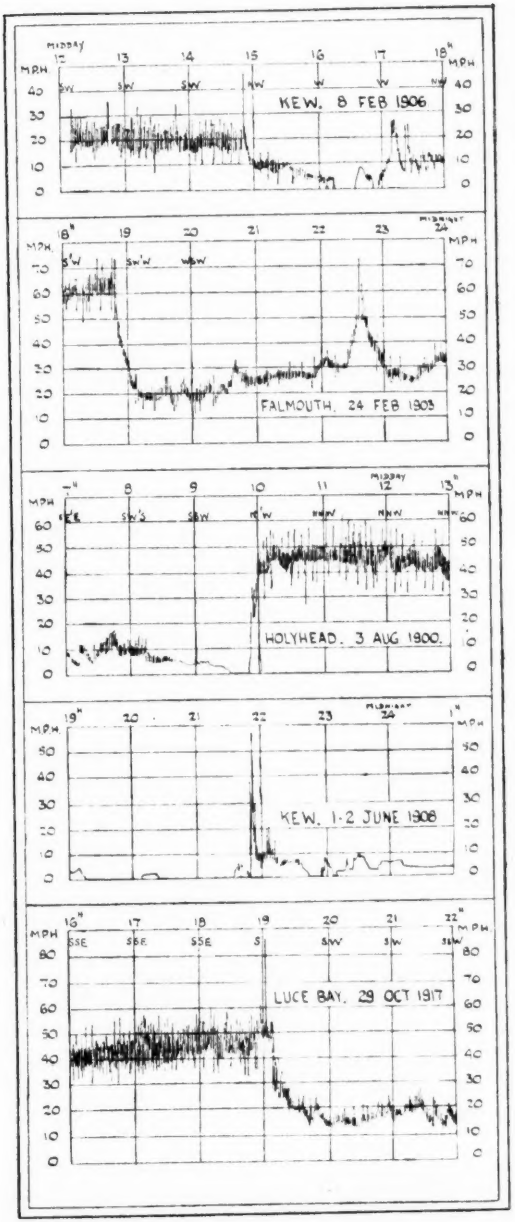


FIG. 15. VARIETIES OF ANEMOGRAMS DURING PASSAGE OF FRONTS

11 Reciprocal Relationship Between Line-Squalls and Thunderstorms

We have seen in paragraph 8 that a line-squall may pull the trigger and give rise to a thunderstorm. It is of importance to realise that when a thunderstorm becomes started in any other way, the rain or hail after a time may cool the air beneath it below the temperature of the adjacent air. If the thunderstorm is being carried along in an upper current the cold air beneath it will cut into the adjacent warm air, and the passage of such a system past a station shows all the characteristics of a line-squall with thunder. Indeed the length of front in some cases would justify them being regarded as line-squalls, the only difference being that the cold air associated with them is merely the limited mass cooled by the rain or hail and not a mass of polar origin extending for hundreds of miles behind the front. It should be mentioned that even in the case of the true line-squall, the cooling effect of the precipitation may still be present, so complicating the structure to some extent.

12 Warnings of Line-Squalls

The warning organisation, the possibility of which was mentioned by Mr. Cave in his lecture of May, 1917, has now long been in operation. All official observing stations maintained by the Meteorological Office report immediately in code to the Air Ministry, usually by wireless, when they experience a line-squall. Stations in the west also warn those in the east direct. Line-squalls likely to affect civil air routes are notified by the Air Ministry by wireless to Paris, Cologne, Brussels and Amsterdam, and the latter services reciprocate. Warnings are also made available at Croydon for notification to pilots and to any aircraft in flight that may be affected. All Royal Air Force aerodromes are warned of the approach of line-squalls by the Aviation Forecast Service at the Air Ministry. The code employed in all these warnings is in accordance with the recommendations of the International Commission for Air Navigation.

13 Waterspouts and Tornadoes

Waterspouts and tornadoes are by far the most intense form of atmospheric disturbance known in nature. They are essentially the same phenomena, the former occurring over the sea and the latter over the land. They occur in association with line-squalls and thunderstorms, and there is much evidence to show that in the case of line-squalls the seat of their occurrence is the region of strong air convergence at *F* of Fig. 12. There is a great tendency there for the formation of narrow whirls of approximately vertical axis extending from the ground up into the squall cloud. These are probably usually present in some degree of intensity, accounting for some of the outstanding gusts on the anemogram during the passage of the squall. If the spin attains sufficient rapidity the reduction of pressure in the core, which balances the centrifugal force, causes adiabatic cooling of the air and, if sufficient moisture is present, condensation takes place, the whirl becoming visible as a waterspout or tornado. Three such waterspouts were visible in the position indicated in Fig. 12 in the Aberdeen case already described and a reproduction of a sketch of them accompanied Dr. Simpson's lecture. The outstanding gust at Luce Bay, shown in Fig. 15, was probably due to a spin of this character, though possibly not rapid enough to produce a visible tornado.

The height from the ground to where they join the cloud is commonly of the order of 2,000 feet, and the diameter is only a fraction of this, sometimes a small fraction, but the dimensions may sometimes be greater. The spin is known in intense cases to be sufficient to give wind speeds of 100 to 200 m.p.h. The length of life of any particular waterspout or tornado is, as a rule, only a matter of minutes (ranging up to an hour or so in pronounced

cases such as some intense tornadoes in the United States), but during that time they may cover a number of miles as they progress with the system with which they are associated. The spray from the sea or dust from the land at the base may be raised some hundreds of feet in the generally rising air of the vicinity. Intense phenomena of this kind have been observed not infrequently even in Europe, but the United States and Australia are the regions where they are most developed. Even there the chance of any individual spot being struck by a violent tornado is very small indeed.

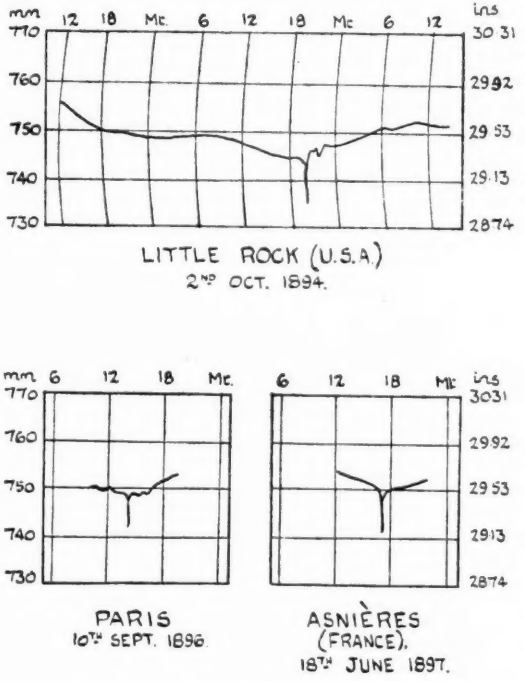


FIG. 16

TORNADO BAROGRAMS.

(*Bibliography, Items* 9 *and* 12.)

Figs. 17 and 18 show places in France and Germany, respectively, where well developed phenomena of this character have been recorded in the course of many years. Fig. 19 shows the parts of the United States chiefly affected by tornadoes. The darkest shading indicates the area of highest frequency. It has been stated that not more than three or four "really destructive" tornadoes occur in the United States each year. The possible danger to life has been estimated as follows: About 50 a year are recorded of which about 20 do considerable damage. The area of destruction is seldom greater than one square mile. Hence, about twenty square miles are thus affected. The region in which tornadoes mainly occur embraces a million and a quarter square miles.

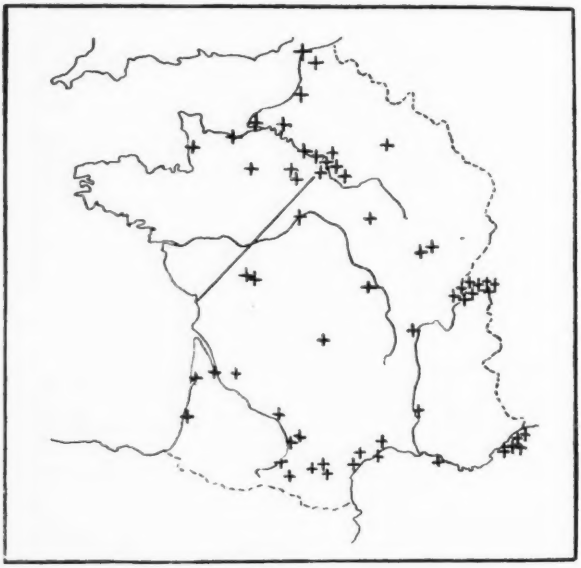


FIG. 17.
Places where Tornadoes have been recorded in France.
(Bibliography, Item 9.)

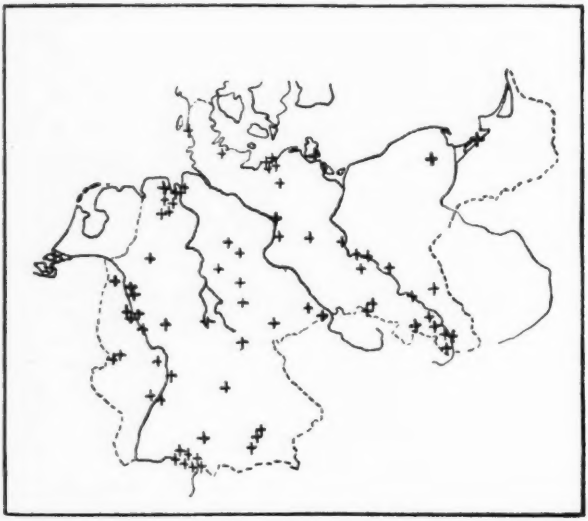


FIG. 18.
Places where Tornadoes have been recorded in Germany.
(Bibliography, Item 9.)

The chance that a tornado, capable of considerable damage, may, in any year, cross the particular locality where any individual may happen to be is thus one chance in 62,500.

Waterspouts are observed much more frequently in low than in higher latitudes. They are not infrequent in the Mediterranean. They are very frequent during the change of the Monsoon in the Java seas. They are sometimes observed in the "Doldrums." Fig. 20 shows the equatorial region of the Atlantic, the numbers in the upper left hand corner of each square indicating the number of waterspouts in that square recorded in the logs of 1,159 British ships passing through this area during the period 1854 to 1871. Since the number of ships passing through the various squares is not the same, the numbers in these different squares are not strictly comparable, but there is a clear indication of a maximum frequency between latitudes 0° and 10° N., the region mainly occupied by the "Doldrums."

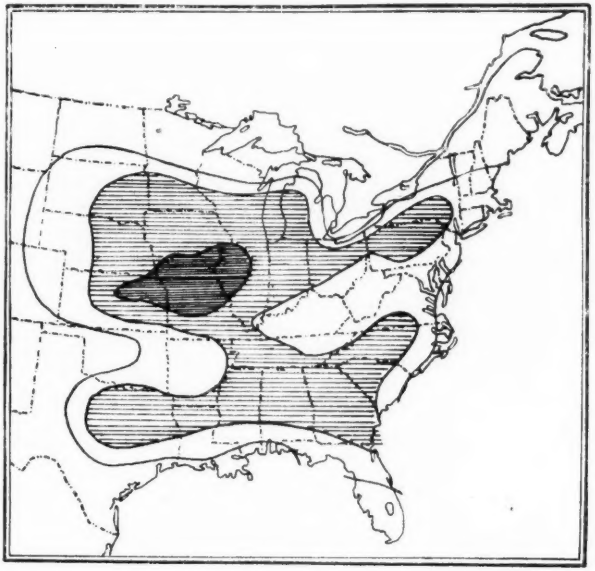


FIG. 19.

Distribution of tornadoes in the United States.
(Bibliography, Item 10.)

Waterspouts are not necessarily associated with true line-squalls, but also with local thunderstorms, probably however with those which have acquired line-squall characteristics as described in paragraph 11.

The position of the whirl shown in Fig. 12 would imply its passage over a station at the time of commencement of the rise of pressure after the preceding fall. In spite of the localised nature of the whirls some have passed over barographs. Three examples of the resulting barograms are shown in Fig. 16. All show a considerable depression of very short duration marking the passage of the whirl with rising pressure afterwards. The Little Rock example is specially good. The difference of pressure between inside and outside of the whirls in these cases was at least some six millimetres or eight millibars. It may have

been more if the centre of the whirl did not pass over the instrument. There is a case on record at Bizerta, N. Africa, of a measured difference of 34 millimetres or 44 millibars. The static differences of pressure involved over short distances may thus be comparable with the dynamic pressures of the winds, for a pressure of eight millibars is, for example, the mean pressure of a wind of hurricane force (75 m.p.h.) on a disc of one square foot in area exposed normally to it. Much of the damage done by tornadoes is due to the bursting outwards of closed structures such as buildings, when the static pressure outside falls suddenly.

There is not time in this lecture to do justice to the important subject of these whirls, but I will quote from a description of a famous United States tornado known as the "Delphos" tornado, given in Abercrombie's *Weather*:—

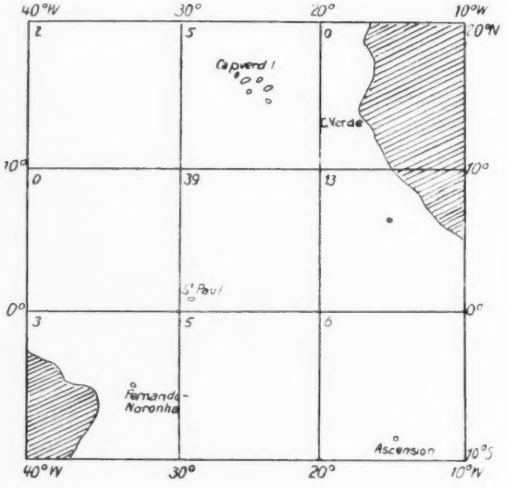


FIG. 20.

Illustrating occurrence of Waterspouts in Atlantic Doldrums.

(Bibliography, Item 11.)

"'On Friday morning, May 30th, 1879, the weather was very pleasant, but warm, with the wind from the south-east, from which direction it had blown for several days. About 2 p.m. threatening clouds appeared very suddenly in the west (against the wind), attended in a few minutes by light rain, the wind still in the south-east. It stopped in about five minutes and then commenced again, wind still the same, accompanied by hail, which was thick and small at first, but rapidly grew less in quantity and larger in size, some stones measuring three and a half inches in diameter, and one was found weighing one-fourth of a pound. This last precipitation continued for about thirty minutes, after which a cloud in the shape of a waterspout was seen forming in the south-west, and moving rapidly forward to the north-east. There was but one funnel at first, which was soon accompanied by several smaller ones, dangling down from the overhanging clouds like whip lashes, and for some minutes they were appearing and disappearing like fairies at a play. Finally one of them seemed to expand and extend downwards more steadily than the others, resulting at length in what appeared to be their complete absorption. This funnel-shaped cloud now moved onward, growing in power and size, whirling rapidly from right to left, rising and descending and swaying from side to side. When within a distance of three or four miles, its terrible roar could be heard, striking terror into the hearts of

the bravest.' *A few minutes previous to and during the passage of the funnel, the air was very oppressive: but ten minutes after the wind was so cold from the north-west* that it became necessary to wear an overcoat when outside. As the tornado struck the house, another member of the family says, 'We think it is coming near us. We can now see its fury. Shall we leave the house? No; for we are not certain on which side it will pass. We are apparently as safe here as elsewhere. The windows are nailed fast. Three of us lean against the door which is nearest the storm; the rest go into the cellar. It is about 4 p.m. A moment of breathless suspense and the storm strikes us. The timbers creak,

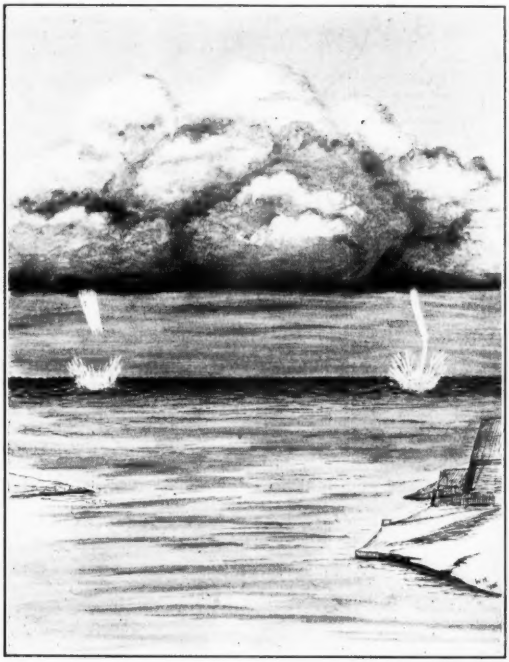


FIG. 21.

Sketch of two waterspouts observed by the Author from Malta.

the sides of the house sway in and out; surely they cannot outlast it. We hear no well-defined roar now, for on the outside, boards and other debris are fiercely crashing. All is dark within. In about fifteen minutes the storm is over. We leave the house. The centre of the storm has passed to the west of us, and we can see its dark form moving away in a north-east direction.'

"The actual diameter of this storm appears to have been only forty-three yards.

"As a specimen of the damage done, a large two-horse sulky plough, weighing about seven hundred pounds, was carried a distance of twenty yards, breaking off one of the iron wheels attached to an iron axle one and three-quarter inches in diameter. A woman was carried to the north-west two hundred yards, lodged against a barbed wire fence and instantly killed. Her clothing was entirely stripped from her body, which was found covered with black mud

and her hair matted with it. A cat was found half a mile to the north-west of the house, in which she had been seen just before the storm, with every bone broken. Chickens were stripped of their feathers, and one was found three miles to the north-west.

FIG. 22.

Die Wasserhose vom 19. Juni 1905 auf dem Zugersee, nach einer im Besitz der Meteorologischen Zentralanstalt in Zürich befindlichen Original-Photographie von Wei 6.

Bibliography, Item 9.

"A few miles further on, another eye-witness says, 'The dark, inky, funnel-shaped cloud rapidly descended to the earth, which reaching, it destroyed everything within its grasp. Immediately after passing the town, there came *a wave of hot air, like the wind blowing from a burning building. It lasted but a short time. Following this peculiar feature, there came a stiff gale from the north-west, cold and bleak*, so much so that during the night frost occurred and water in some low places was frozen.'"

It will be noticed on referring this description to Fig. 12 that the warm air well forward from the cold wedge must have been very unstable, the rain and hail falling before the tornado was visible. But the main interest lies in the

FIG. 23.

Photographie der Wasserhose von Cottage City (Nordamerika) Photographiert von L. N. Chamberlain.

Bibliography, Item 9.

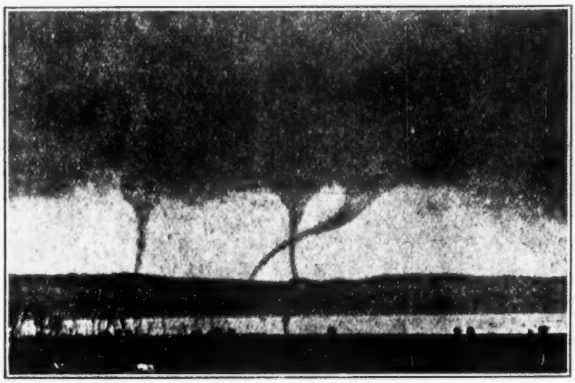


FIG. 24.

Photographie dreier gleichzeitiger Wasserhosen in Neuseeland von Bates (nach v. Hann).

Bibliography, Item 9.

portions of the quotation which have been put into italics. Two independent observers noted the short interval of time between the incidence of the tornado and of the cold north-west wind, the hot blast intervening corresponding presumably to the portion *EC* of Fig. 12.

Fig. 21 shows a sketch of two waterspouts which I observed looking in a north-easterly direction from Malta about 07.55 G.M.T. on December 5th, 1925. Without entering into a complete discussion of this case, it is useful to remark that the duration of the spout on the right as a visible spout was four minutes, but that the existence of the spin both before and after the visible stage was proved by the throwing up of the spray at the base during those phases. Further, the two spouts were definitely associated with a secondary cold front which later passed Malta. The chain of cumulus along the front is seen in the sketch, and the incidence of the squall wind along the line joining the spouts was definitely shown by the smooth sea up to that line and the rougher sea with white breakers beyond it.

Photographs of three other cases are shown in Figs. 22, 23 and 24. In one case (Fig. 24), relating to New Zealand, three complete spouts are seen existing simultaneously in a line, and the cloud above them appears to have the linear character of that associated with a cold front. Figs. 22 and 23 refer to Switzerland and North America respectively.

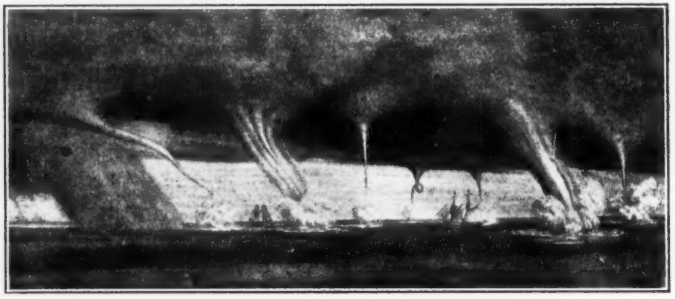


FIG. 25.

Erscheinung von Wasserhosen, beobachtet in den Gewässern von Sizilien in Sicht des Stromboli am 27. Juni 1827 und gezeichnet von L. Mazzara an Bord der Brigantine le Portia, Kapitän Cabbage, in dem Augenblick, wo das Schiff auf die es am nächsten bedrohende Wasserhose feuert. (Nr. 83 des Verzeichnisses; aus Platzgründen mußte das Bild auf der linken Seite, wo der Stromboli und noch zwei weitere ferne Wasserhosen sichtbar waren, etwas gekürzt werden. Original im Besitz der Deutschen Seewarte.)

Bibliography, Item 9.

Finally, in case I have not inspired you with sufficient awe of these phenomena, you will see in Fig. 25 a most remarkable sketch of waterspout phenomena observed in the waters of Sicily on June 27th, 1827. This is admittedly only a sketch, but it cannot be regarded as entirely fantastic. The arrangement of the spouts in lines, in association with a heavy cloud mass of obvious linear character, is in accordance with the views which have been developed in the earlier parts of this paragraph.

14 Conclusion and Acknowledgments

In conclusion, I would like to say that the picture I have endeavoured to present of the detailed structure of line-squalls is undoubtedly not the final picture which will be arrived at as knowledge progresses. It is probable, how-

ever, that further research will not modify the essentials which are certainly well supported by the evidence available to-day.

There are many points for further investigation which hold fascinating possibilities, and on which, had time permitted, I might have thrown more light even on the basis of present knowledge. There is the question of minor local variations in the rate of advance of line-squalls; the effects where line-squalls meet hills and mountains; the possibility of periodic fluctuations in the rate of advance due to atmospheric waves at the sloping boundary of the cold and warm air, or the analogy of the manner in which the tide comes in on a sloping beach.

FIG. 26.

Large Hailstones at Dallas, Texas, May 8th, 1926.

Bibliography, Item 8.

In addition there is the important question of the application of radio goniometric methods to the location of thunderstorms and the possibility of carrying such apparatus in aircraft partly with a view to determining at a distance, along which parts of a line-squall thundery conditions are most or least developed. On this point I hope we shall hear something in the discussion.

In a lecture of this character in which many sources of information are drawn upon, it is not convenient to acknowledge each in the course of the lecture itself. Accordingly a short bibliography is appended giving some of the principal publications to which reference has been made, apart from those already mentioned, and in some cases where a diagram has been copied the number of the corresponding figure accompanying this lecture is given in brackets.

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9. A. Wegener, "Wind—und Wasserhosen in Europa." Braunschweig, 1917. (Figs. 16, 17, 18, 22, 23, 24, 25.)
10. R. De C. Ward, "The Tornadoes of the United States as Climatic Phenomena." *Quarterly Journal of the Royal Meteorological Society*, Vol. XLIII., 1917, pp. 317-329. (Fig. 19.)
11. G. Hellmann, "Wasserhosen auf dem Atlantischen Ocean." *Sitzungsberichte der Preuss. Akad. der Wissenschaften*, XXX., 1925, pp. 539-544. (Fig. 20.)
12. E. Durand-Gréville, "Boën und Tornadoes." *Met. Zeits.*, January, 1897, pp. 8-21. (Fig. 16, Little Rock Barogram.)

Discussion

Colonel the Master of Sempill: I now feel more overwhelmed with awe than ever of the line-squall, especially after seeing the last picture. I have had the fortune or misfortune to come through or over several line-squalls—probably not very severe ones—but since hearing Mr. Giblett's lecture I shall be inclined to give them a wide berth.

I would not have missed this lecture for anything—nor, I am sure, would any of this audience—because it puts before one an immense amount of information that is new. It has been put in such a form that it can be readily absorbed by anyone, even those with no great knowledge of meteorology. Our thanks are due to Mr. Giblett for the enormous amount of work he has done in collecting and arranging this information. I was particularly gratified to see the interesting and beautiful pictures of line-squalls at my native town of Aberdeen (reproduced in this Journal in Dr. Simpson's lecture on "Thunderstorms and

Aviation " delivered November 27th, 1924) and am sure the audience will realise how many are the good things that Scotland has to offer. Mr. Giblett's theory of the origin of and sequence of events during his passing of a line-squall will arouse great interest and some controversy.

Major G. H. Scott: Interested as everyone here must have been in listening to this paper, I feel that to nobody could it have had such an intense interest as myself and the other officers connected with airships. Every type of craft has some special danger to fear. Steamships fear icebergs, aeroplanes fear fog and low cloud, neither of these constitute a danger to airships, but the strong vertical currents associated with line-squalls probably constitute the airship's most dangerous enemy, so that anything that can give us more information about these line-squalls is of immense value. I feel that Mr. Giblett has greatly advanced our knowledge by his detailed description of the structure of line-squalls. When a danger has to be faced, it is of great assistance in avoiding or getting round it, if it is possible to visualise it and know something of what is actually happening. I think the way in which Mr. Giblett explained the actual motions of the air that occur in a line-squall during the passage of a cold front will be of immense assistance to all airship pilots.

There are so many points of interest in the paper that it is impossible to do it justice in a few minutes, it needs close study. I was, however, particularly interested in Mr. Giblett's statement that the vertical currents depend to a very large extent on the conditions of the warm air in front of the cold wedge; and that if this air is in an unstable condition thunderstorms will probably occur, whereas if the air is stable the probability of thunder is small. An airship in flight, having been warned by a meteorological report of the approach of a line-squall can survey the air; that is, plot the temperature at various heights; it will then have some idea as to how serious the vertical currents are likely to be and the decision taken whether to avoid the squall or go through it, also as to whether the position is a good one to go through or a position where the air is more stable should be looked for.

After seeing Mr. Giblett's pictures of hailstones, I think the only consolation is that hailstones of this size must damage everything they hit—houses, motor cars, and so on, yet people continue to build houses and motor cars. This picture should therefore not be used as an argument against the building of airships.

Everything Mr. Giblett has said tends to further demonstrate the acknowledged necessity of the provision of an adequate system of meteorological forecasting, if airship transport is to be run with the safety, regularity and economy that is desired.

On behalf of all those interested in airships, I must thank Mr. Giblett for this paper and the very definite advance it contributes to our knowledge of line-squalls.

Lieutenant-Colonel Richmond: I should like to express my admiration for the way in which Mr. Giblett has so ably disentangled the various physical processes which go to the formation of a line-squall. In particular the temperature phenomena which he has described greatly interests me.

The vertical equilibrium of an airship may, of course, be just as seriously affected by local temperature and density variations as it may by aerodynamic forces arising from vertical currents. The possible rate of vertical rise of an airship is, of course, of prime importance in connection with the design of the automatic valves. In an early discussion with Mr. Giblett on this subject he gave it as his opinion that the air velocities might be anything up to 8,000 ft. a minute in the centre of a severe thunderstorm. It is, of course, possible to find a vertical rate of rise which no airship could be expected to withstand and

which might, as Mr. Giblett has shown, destroy such a solid structure as a public building.

An examination of the valving capacity of airships which have been built in the past leads one to the conclusion that their maximum safe rate of vertical rise was of the order of 1,000 ft. per minute. In my opinion this is too low, and by the use of a new form of automatic valve I hope that in R.101 we shall be quite safe as far as valving capacity goes, with a vertical rate of rise of as much as 4,000 ft. a minute.

The effect of a line-squall meeting an airship riding at a mooring mast is also a problem of special interest. The Meteorological Office have experiment in hand with a special set of masts at Cardington, to analyse the composition of squalls passing over the aerodrome, and methods of working out the stresses caused in the ship when riding at a mast by such squalls have been worked out. These matters have, however, been so fully described before this Society on previous occasions that I do not propose to dwell on them any further here.

Dr. SIMPSON: There are one or two points on which I would like to say a few words. Most of you will have noticed that throughout the paper aeroplanes and airships are not mentioned. This is how it should be, for it is not the business of the meteorologist to say whether or not line-squalls or thunderstorms are a danger to aircraft. He must simply state the facts and leave the airmen to draw their own conclusions.

I have, myself, considerable confidence that Colonel Richmond has designed an airship which will meet practically everything that it is likely to experience in the air and I am sure that Major Scott will successfully navigate the ship through all its difficulties, but we cannot ignore the dangers, if for no other reason that we do not know how great the danger may be. It will therefore be wiser to run away from the dangers than to meet them. This means that the great problem will be one of forecasting. Forecasts throughout the whole route, no matter how long, must be provided. This will be an extremely expensive matter; but it will have to be faced. It is fortunate that just at this time the science of forecasting has been greatly improved by new discoveries of the structure of the atmosphere. It is a remarkable fact and one of which meteorologists may be proud that these discoveries have been made largely independently of aviation. Kites, registering balloons and mountain observations have provided most of our new knowledge. We are now getting information from aeroplanes and it is extremely valuable information and is largely used in our forecasts.

Forecasting for airships is going to be a very great responsibility. The chief difficulty is that conditions frequently approach the danger line without crossing it. So at first there may be some danger of crying " wolf " unnecessarily. Still it will be better to err on the side of safety than to take too many risks.

I think meteorologists as well as the airship operators are to be congratulated that there was a man like Mr. Giblett available when the Airship Meteorology Division had to be established. No one knows the science better than he. He has remarkable organising powers, business ability and a personality which make him friends wherever he goes.

Group Captain P. F. M. FELLOWES: First I should like to add my congratulations to those which have already been proffered to Mr. Giblett on what I think I may describe, without exaggeration, as a brilliant and penetrating analysis of the particular aspect of meteorology which he has selected for his lecture. I should also like to associate myself most warmly with everything that Dr. Simpson has said with regard to the lecturer.

It struck me when listening to his lecture how much meteorology has developed lately and how strange it is that those things which have always been happening in the atmosphere have never been investigated before. Perhaps wire-

less telegraphy is the sudden cause of its development. It also occurred to me to wonder whether now that this knowledge has become available, if sailing ships are perhaps going to make themselves capable of taking advantage of this new information by installing wireless sets. Perhaps if the Flettner rotor ships fulfil the hopes of their inventor, they also, as well as aircraft generally and airships particularly, will make use of this new and wonderful science.

At first sight the pictures, which Mr. Giblett so interestingly described, of the forces resident in the atmosphere made me feel rather gloomy until he disclosed the comforting statistical fact that even (to take one example) in the area in the United States where tornadoes are most prevalent the odds against them passing over any particular place in one year are 62,500/1.

From one point of view, I feel that no great human effort at development, such as airships, has ever been allowed to start " by the powers that be " only to be brought to failure by the laws of nature, and from another and more concrete, I am confident that the meteorological network which Mr. Giblett is going to organise for airships will eventually render them comparably as safe as sea-borne ships.

In the past an essential safeguard to the safe passage of surface vessels over the sea was a sufficient comprehension of the laws and rules of navigation and pilotage. Their equivalent for airships in the air will, I suggest, be navigation and meteorology and of these two the latter is the more vital. The sea trade routes of the world are now amply provided with pilotage facilities and equally so in the future must the airship routes of the world be provided with meteorological and wireless facilities.

Professor Sir GILBERT WALKER: I think it may be of interest to the Society to have an account of a type of line-squalls apparently different from those found in extra-tropical regions. I ought to preface my remarks by explaining that in India meteorological observers are not educated men and are often unable to give an intelligent account of what they see; thus in Madras we used to get reports of snow when hail had fallen. So it is difficult to ascertain the exact nature of the disturbances other than cyclones which occasionally do considerable damage, trains being blown off the rails, roofs carried away, and so on. But my main theme is the " nor'-westers " of Bengal, which are well formed line-squalls travelling from the north-west; and yet, as far as weather charts indicate, there is no meeting of cold air and hot air before the squalls are formed. The humidity charts show that the air over the Bay is a good deal damper than that over the land, and there is a definite impinging of dry inland winds on the damp winds from the Bay; my surmise is that convection produces rain which cools the air, the distribution being such that the process maintains itself while travelling south-eastwards. The effect undoubtedly is the formation of typical line-squall clouds a number of miles long. Also, although the mode of formation is rather uncertain, the occurrence of nor'-westers is an almost certain consequence of a definite type of pressure distribution with the ordinary trough of low pressure extending into the south-west of Bengal.

Colonel GOLD: There are two aspects of the paper which make a special appeal to me. The first is general—the way in which Mr. Giblett has tried to get a common explanation of widely distributed phenomena occurring all over the world, which previously were looked upon rather as isolated occurrences. That appeals to me because until we get a proper explanation of these phenomena we shall not be convinced that we can always get out of the way of danger. At the present time there are a number of occurrences in the atmosphere which are not visible, and we are not likely to be able to identify them until we can give a reasoned account of what we can see. Whirls extending to the surface of the earth are practically always rendered visible, but if they occurred at 5,000 or 10,000 feet it is not at all certain that they would be always visible.

The second point was the detailed examination of what goes on at the cold front. Meteorologists have had in the past many examinations of line-squalls, but I think this is the first time that anybody had had the courage and ability to depict the cold front on a scale of about four miles to a foot—it has previously been a case of 10 or 100 miles to the inch. On this occasion we have a real picture of what is likely to be happening on the cold front itself. That is all to the good because it is only by developing an explanation such as this that we shall get an understanding of the physics of the cold front.

It is sometimes assumed that dangers only occur in America or on other large continents, but they may also occur in this country. A tornado crossed South Wales in October, 1913. On that occasion the disturbance travelled from the Channel to Lancashire; it was not excessively bad at first, but when it got to South Wales it became very violent. It tore off corrugated iron roofs and wrapped them round telegraph posts miles away, picked up cows and carried them to neighbouring fields and wrecked buildings. As Major Scott said, whether you were in an airship or a motor car in such conditions, it would be dangerous. Such occurrences are extreme ones which are put on record on that account, but some not recorded can constitute real dangers to aeroplanes and airships. Mr. Giblett mentions the reduction of pressure in the waterspout. If this is computed on the hypothesis that air is moving inwards to the spout, so that angular momentum remains constant, the reduction for a speed of 200 miles per hour would be about 50 millibars. There are evidences of speeds of 200 miles per hour being reached in tornadoes and waterspouts, but until Mr. Giblett drew my attention to the record in the Mediterranean I had not seen an actual barometer record for the centre of a waterspout or tornado with so large a reduction of pressure. [In a record near the centre of the South Wales tornado the reduction was only 10 millibars.] A reduction of pressure of 44 millibars would be quite sufficient of itself to form a cloud in the waterspout without any rain or spray entering from the cloud above or the sea beneath.

Wing Commander T. R. CAVE-BROWNE-CAVE: I think this Society has been very fortunate in having had Dr. Simpson's and Mr. Giblett's papers. Both these papers have presented in an easily intelligible form very important aspects of meteorology which were previously obscure. Next year we must ask for some paper on essentially the same lines.

That picture, Fig. 12, which Mr. Giblett drew to show what is happening on the cold front during the passage of a line-squall does impress on one's mind the whole process. If you can visualise exactly what is happening it is far easier to avoid it.

I was particularly struck by the Author's sketch of a waterspout at Malta. There was an enormous amount of detail, and one admires the power of observation which can absorb so much in such a short space of time.

I was glad to find in the paper particulars of the great variations of temperature and pressure met with in line-squalls. I suppose these would not have an effect on an airship at the mast because she would get sufficient warning of a serious disturbance to enable her to depart from the mast before the storm's arrival.

Colonel Richmond referred to the serious consequences of the change of direction of the velocity of the wind. Is not the rapid change of temperature equally serious?

I should like to add a tribute to Mr. Giblett as an observer and a lecturer. I think it is a great pity that more is not done to make meteorology as interesting to people in general as Dr. Simpson and Mr. Giblett have shown it can be.

Captain ENTWISTLE: While I agree with Dr. Simpson's remarks regarding the progress of meteorology, I should like to suggest that the recent advance in

our knowledge of the performance of the atmospheric machinery—of which this paper is an outstanding example—has been stimulated by the demands which have been made on meteorology by aviation. I am sure that in preparing this paper Mr. Giblett was considerably stimulated by the inside knowledge which he had obtained in carrying out investigations to meet the meteorological requirements of airships.

The point in the paper which interested me most was the detailed description of the structure of the line-squall, and I should like to emphasise that this is the first time that this detailed picture of the structure of line-squalls has been put forward. I was extremely interested to see that Mr. Giblett's ideas have since been confirmed by the actual observations which Mr. N. K. Johnson has made.

Mr. Giblett has referred to the organisation for the warning of line-squalls, and I should be rather interested to know how far heavier-than-air pilots regard the line-squall as a dangerous, as distinct from unpleasant, phenomenon. In the map which is exhibited at Croydon giving the hourly weather reports from stations on the civil air routes, the symbol for a line-squall is in red with a black circular arrow painted on it. I remember a certain air official asking why that symbol was painted red because, he said, pilots did not worry about line-squalls. The organisation for warnings to aircraft of the imminence of line-squalls, which has been drawn up with the full approval of those responsible for aviation, hardly bears this out. Such warnings have certainly been of value in the case of aircraft on the ground. I can recall more than one case where a timely warning has ensured that the aeroplanes have been put in the hangars, whereas had they been left out on the aerodrome unprotected they would almost certainly have been damaged.

Additional Note.—It is probable that a "warm front," which is referred to in the earlier part of this paper, is of equal, if not of greater, importance to the heavier-than-air pilot than the "cold front" with which line-squalls are associated. The passage of a warm front is frequently accompanied by very low cloud, rain or drizzle and mist, whereas in the case of a cold front, apart from the localised heavy rain, visibility is usually good.

Captain BROOKE-SMITH: As the direct descendant of Noah of the Ark, I should like as a master mariner to thank Mr. Giblett for so ably putting before airmen the conditions and dangers of squalls, whirls and thunder storms, because I think it may be shown how much the Merchant Service may do to help them in the promotion of rapid Empire communication overseas.

At sea we constantly see the evidence of terrific vertical as well as horizontal winds aloft and I will give you just one experience which is in my memory.

In November, 1895, in the ship "Syren," Captain Malcolm Maclean when running our Easting down from Cape Town to Sydney. One night we were bowling along under all plain sail with a strong N.W. breeze, the barometer was falling and by and by a long heavy cloud showed up to windward. Sail was reduced to top gallant sails. The rain came and it was very heavy and there was terrific thunder and lightning.

The order was stand by the top gallant halyards.

"When the rain's before the wind,
Your topsail halyards you must mind;
But when the wind's before the rain,
You may hoist your topsails up again."

Presently there was a terrific flash of lightning followed by deafening thunder and a crash up aloft, fire passing down the main skysail and royal backstays.

Soon after this there was a break in the clouds to the S.W. and the order was "port fore brace" not a moment too soon, for the lee leach of the main topsail began to lift. "Starboard your helm, haul away port fore brace."

Well, all this means that there was a sudden shift of wind to the S.W. and that the helm was used and yards trimmed to prevent the ship being caught by the lee.

The wind now increased and it blew from the S.W. I think it was on this day that we ran 355 miles, our best run. When daylight came we found that the lightning had split the main skysail royal and top gallant mast—a long spar—down to the topmast cap, passing down the backstays, cutting the service from them and passing through the steel hull into the sea. There must have been great aerial currents set up aloft.

Notwithstanding the reduction of sail necessary in strong winds the passage was made in 29 days, which is, I believe, the world record from Cape Town to Sydney.

Now the knowledge gained by experience, which Captain Maclean had, which enabled him to know exactly what to expect in the change of direction and force of the wind at the surface is natural knowledge which is common to the officers of the Merchant Service.

Something was said of fear. I do not believe that that enters into the matter with airmen. I think that with them it is as with us and what matters is good airmanship just as we consider good seamanship. It is a matter of doing the right thing according to information available.

We may not have profound scientific knowledge of the process of nature in the atmosphere, but our observation and natural knowledge and experience may be made available for the information of aerial navigators by means of wireless telegraphy if proper encouragement is given. And I suggest that the best encouragement which can be given is to take the Merchant Service into your confidence by telling us exactly how we can help you, remembering that our conservatism comes of hard experience.

I believe that better facilities may be obtained as aids to navigation regarding wireless direction finding, wireless communication and meteorology to the mutual benefit of the sea and air services by cultivating mutual understanding of the requirements of the Merchant Service of the sea and Commercial Service of the air than could ever be obtained by the demands of one independent of the other.

Mr. BRUNT: I should like to explain the observational data which confirm the detailed structure of a line-squall shown in the diagram which Mr. Giblett has put forward. By permission of the Post Office authorities we have been able to fit recording instruments at intervals on wireless masts 300 feet high. The records give the differences of temperature at 300 feet and 200 feet, at 200 feet and 100 feet, etc. When a cold front passes, the difference in temperature at 300 feet and 200 feet is of about the same magnitude in the cold and warm air, but just at the time of passage of the front there is a sudden increase in the difference of temperatures at the two heights, indicating the arrival of the cold air at the higher level some few minutes earlier than at the lower level. Knowing the time taken for the cold air to reach successive levels from 300 feet to the ground, and the force of the wind, we can readily compute the inclination of the cold front at low levels. In the first case that was noticed, the slope was of the order of one degree.

I do not think that forecasting for airships will be an impossibly difficult task, since the forecaster will have a perfectly definite operation in view. The meteorologist who forecasts for the daily Press has not this advantage, since each reader of his forecast may require it for a special purpose of his own.

Captain C. K. M. DOUGLAS: I should like to say something from the point of view of an aeroplane pilot, having had some years' experience during and just after the war. During that period I was occasionally in difficulties through

fog and low clouds, but never owing to a squall, and my experience was probably typical in that respect. At the same time one ought to know something about squalls. An experienced pilot might have weathered many squalls successfully and yet get into trouble if he tried to get through an exceptionally severe one at a low level below the clouds. If it is impossible to get round such a squall, I think it is best to try to get through the clouds high up. The tops of the thunder clouds spread out into an extensive "anvil" consisting largely of snow, which may extend up to 30,000 feet and forms a more or less continuous mass of cloud. Parts of the anvil merge into great columns of cumulo-nimbus clouds, with powerful rising currents and hail and snow, and usually thunder and lightning. My experience has been that there are relatively weak spots in the anvil, where it is fairly easy to get through and which with experience can be readily detected. Further investigation is required to discover whether there are always such easy places, and in particular whether an airship could get through without serious risk of being involved in a strong rising current.

I think some additional emphasis might be placed on the mutual action between line-squalls and thunder storms discussed by Mr. Giblett in paragraph 11. The majority of line-squalls reported are really local thunder squalls developed in the body of the polar air. There is frequently a fall of temperature of about 5°F., doubtless owing to the rain or hail, followed by recovery of the temperature to about its original level. These squalls are sometimes in lines of the order of 20 miles long, which seems to show that slight secondary cold fronts of limited length must have acted as "triggers." I think, however, that Mr. Giblett was justified in devoting a good deal of space to the polar front, since if there does happen to be a severe squall along the cold front it is serious owing to its great length.

Mr. R. A. Watson Watt: I share the admiration which Colonel Gold has expressed for the ingenious and generous way in which Mr. Giblett, promising us no more than a discussion of line-squalls, has given us in fact a brief and extraordinarily graphic manual of modern meteorology.

As Mr. Giblett has said, we are trying, at the Radio Research Station of the Department of Scientific and Industrial Research, to see whether we cannot help towards a more complete knowledge of meteorological conditions by the study of atmospherics. I have here a few slides illustrating the way in which radio-telegraphic stations receive natural signals of disturbance. The first three slides show the synoptic charts for three successive days, tracing the progress across Europe of a typical cold front, of which successive positions are shown on the fourth slide. The predominant sources of the atmospherics located by direction finding were, as can be seen from the plotted locations, closely associated with the cold front, and two automatic recording installations in Great Britain succeeded in keeping in touch with the cold front throughout its passage over nearly 3,000 kilometres in 40 hours. The next slide shows the tracing by two recording stations in Great Britain and one in Egypt of the southward progress of a cold front over the Mediterranean.

These are examples of the application of direction finding to meteorology on the large scale, but it is perhaps more important still that we should try to help the navigator to find a comparatively quiet route through a disturbed area. The sixth slide shows how, by the use of a device capable of showing visually the direction of arrival of each individual atmospheric, an undisturbed track may be followed through a complex distribution of local thunder storms. The example shown involved the use of an extensive aerial system, and Major Scott not unreasonably represents that he cannot carry twenty acres of aerial on H.M. airships. I am therefore glad to say that recent work enables us to promise that the apparatus can be made sufficiently compact for practical use in airships.

Colonel SEMPILL: It seems to me that this very valuable paper emphasises two things—firstly, that we owe a very cordial vote of thanks to Mr. Giblett and those associated with him; and secondly, the importance of securing complete information of these extreme phenomena in all parts of the world to Major Scott and those responsible for the development of airship routes. I would like to ask as to what steps are being taken to secure this information in the Tropics in particular and when it will be available. Captain Entwistle has rightly drawn attention to the importance of such information to those concerned with heavier-than-air craft. In the past there has been much discussion as to whether water in the waterspouts seen at sea was condensed from the atmosphere or sucked up from the sea. Both ideas have been advanced separately and it now appears that both conditions occur at the same time. I confess this is new to me. I have been through a few line-squalls and can speak with some feeling of the intense vertical currents met with. I remember on one occasion the aneroid measured several changes of height of 800 feet in under a minute. The sensations are not over pleasant, largely because the movements cannot be controlled. It does not appear, however, that a line-squall need seriously inconvenience aeroplanes. The pilots of commercial aircraft being particularly careful of the internal economy of their passengers would avoid them as far as possible.

REPLY TO DISCUSSION

Mr. GIBLETT: I am very grateful to Sir Gilbert Walker for his description of the "north-westers" which occur in the Calcutta area. These "north-westers" appear to furnish a very good example of the reciprocal relationship between line-squalls and thunder storms referred to in paragraph 11 of the paper. There is another interesting phenomenon of the same character which occurs in W. Africa, namely, the so-called "tornadoes." These are not tornadoes in the ordinary sense of the word, but are thunder storms sometimes extending along a considerable front, which move outwards towards the coast of W. Africa. They are very frequent in certain seasons south of Bathurst, especially in the region of Freetown in Sierra Leone, and along the coasts of the Gulf of Guinea. They probably start as thunder storms purely and simply, but they often develop the characteristics of violent line-squalls.

In answer to Squadron Leader Booth's question as to the actual height to which tornadoes extend, it was stated in the paper that the distance from the earth's surface to the point where the tornado is lost in the line-squall cloud is often of the order of 2,000 feet; no doubt sometimes they extend to greater altitudes, perhaps of the order of 6,000 feet. At higher levels still, the conditions are quite different, but may be nevertheless violent, for there the very strong vertical currents of the interior of thunder storm clouds may be encountered.

It was very gratifying to hear confirmation from Captain Brooke-Smith of the potentialities of the co-operation of the Merchant Service in supplying weather reports from sea areas. This will be of extreme importance for the development of long distance airship routes, for these will undoubtedly lie to a very large extent over the ocean. The Merchant Service, in organising its own meteorology cannot help incidentally assisting the world in general and airships in particular.

I am indebted to Captain Brunt for supplying further particulars of the observations of Mr. Johnson, which provide such striking confirmation of the forward slope, in the direction of motion, of the boundary between the cold and warm air near the earth's surface in a line-squall.

The emphasis laid by Captain Douglas on the importance of secondary cold fronts is certainly not misplaced, and because they are called secondary fronts it should not be supposed that they are in general any less violent than the cold fronts of the main polar front itself.

The work of Mr. Watson Watt on the location of centres of thunder storm activity by means of radiogoniometric methods is very promising, and when developed further will in all probability be of the very greatest assistance.

In reply to the questions of the Chairman as to what steps are being taken to fill the gaps in our knowledge of conditions over certain parts of the globe, the answer is that on the one hand certain staff of the Meteorological Office are working purely on investigations for airships, utilising the very comprehensive data and information contained in the Meteorological Office library. Many of the gaps in our knowledge can be filled by co-ordinating these data. Apart from this, every advantage is being taken of the existing network of meteorological observers over the face of the globe, including the sea, to obtain special information.

The Chairman mentioned the previous uncertainty as to the formation of waterspouts. There appears to be little doubt that the visible tube is formed by the condensation of water vapour following on the adiabatic cooling, resulting from the reduction of pressure as the spin increases. Apart from the visible tube, the spray from the sea or dust from the land is carried up to a considerable height around the central tube, and this is in all probability to be attributed to the spray or dust, once detached from the surface by the whirling column, being simply lifted up in the general rising air of the environment.

In conclusion, I should like to thank all speakers for their very kind remarks. I have been fortunate in three ways in carrying out meteorological work on behalf of airships. In the first instance, I have a very loyal and capable staff to help me; I have the generous co-operation of all my colleagues in the Meteorological Office, particularly Captain Entwistle, who is in charge of the meteorological services for aviation (heavier-than-air), which as far as meteorology is concerned must be regarded as the "Senior Service"; lastly, I am particularly fortunate in the fact that all the work which I am doing is done in close co-operation with Major Scott, and I should like to say that every consultation with him results in suggestions from his side, which are likely to be as valuable to meteorology as they are to airships.

The great responsibility which will fall on the meteorological service when supplying weather reports and warnings during the actual operations of the new airships has been referred to. All I can say is that we are conscious of this responsibility, and I should like to assure Group Captain Fellowes that when the time comes we shall face up to it and do our best.

Colonel the MASTER OF SEMPILL: Not many years ago meteorologists were looked upon by pilots of aeroplanes and seaplanes as very amiable but not practical people. That time has long passed and it is due to the collection and proper application of data that we are able to keep up such a high degree of reliability on our air routes to-day. The meteorologists are essential to us and we cannot do without them. The success of long distance airship routes will be assured so far as the meteorological side is concerned, Mr. Giblett will see to that.

ABSTRACTS AND NOTICES FROM THE SCIENTIFIC AND TECHNICAL PRESS

Issued by the Directorates of Technical Development and Scientific Research

AIRCRAFT ENGINES, FUELS AND LUBRICANTS

1 Fuels and Lubricants (Characteristics and Production)

Comparison of fuels by Analytical and Engine Tests. D. R. Stephens and S. P. Marley, Ind. and Eng. Chem., Vol. 19, No. 2. (8.51/5556 U.S.A.)

Eighteen samples of petrol composed entirely of petroleum have been analysed for their content of paraffins, naphthenes, aromatics and any saturated hydro-carbons by the method recently described by Egloff and Morrell. These fuels were then tested for detonating tendency using a direct reading detonation indicator.

Comparison of the benzine equivalents calculated from analysis with those determined by engine tests gave moderate agreement for about half the fuels studied, but there were wide discrepancies.

The Composition of Petrol as indicated by Close Fractionation. (J. B. Hill, L. M. Henderson and S. W. Ferris, Ind. and Eng. Chem., Jan., 1927. Abstracted in J. Inst. Pet. Tech., Feb., 1927.) (8.51/5559 U.S.A.)

Four fuels of known history and origin were fractionated by means of a 5ft. Snyder column with a controlled reflux. Fractions consisting of 2.5 per cent. of the total charge were collected and the sp. gr., critical solution temperature in aniline, refractive index and A.S.T.M. distillation of each were determined. Thus graphs were plotted of the boiling-point at 50 per cent. distillate against sp. gr., refractive index and aniline point.

The curves so obtained show a surprising regularity of peaks and troughs for any one gasoline, while in all four the curves show peaks and troughs in approximately the same places.

A comparison of these curves with corresponding ones for pure paraffins, olefines, naphthenes and aromatics, seems to indicate a high concentration of naphthenes at the peaks, while the troughs show a corresponding high concentration of paraffins.

The similarity of curves in all four shows that the same components are present in each case, differing only in amount, while a comparison of the troughs with the curves of pure paraffins seems to support the view that most of the paraffins present are straight chained.

Much closer fractionation of one of the gasolines gave much higher peaks and correspondingly depressed troughs, as was to be expected.

While the results of this work are of considerable speculative interest the authors do not consider them as warranting conclusions.

Production of Liquid Fuel from Coal. (Ind. and Eng. Chem., Vol. 19, No. 1.) (8.511/5549 U.S.A.)

This Journal contains a symposium on the processing of coal. Articles are included which survey the sources of fuel supply and the various methods of effecting the low temperature cabonisation of coal. The composition of light oils from the low temperature carbonisation of Utah coal is given. The situa-

tion in Great Britain relating to low temperature carbonisation is described by D. Brownlie, and various processes are described.

Makhonine Non-inflammable fuel. (Aviation, 31.1.27.) (8.51/5280 France.)

This fuel is stated to be non-inflammable under normal atmospheric conditions, and it is stated that it can be substituted for petrol with only slight changes in carburettor adjustment. The main basis of the fuel is coal-tar. The French government has been testing this fuel for some time, and it is stated to own all rights to its use.

In Les Ailes, 20.1.27, it is stated that the Air Union has abandoned tests on this fuel, but the reason is not clear. The Air Union drew attention to the solidification of the fuel at low temperatures, but stated that the remedy was simple and that it was in no way a serious obstacle to the adoption of the fuel for aircraft engines. S.T.Ae. are stated to have come to an agreement with the inventor and further tests are to be carried out.

Laboratory Method of Determining Starting Properties of Motor Fuels. (W. G. Lovell, J. D. Coleman and T. A. Boyd, Ind. and Eng. Chem., Vol. 19, No. 3.) (8.82/5571 U.S.A.)

An attempt has been made to devise a laboratory method of determining the readiness with which an explosion may be obtained with any given fuel at the temperature desired. The method consists in measuring directly the air-fuel ratio necessary to produce an explosive mixture at any given temperature. It has been applied to the testing of a considerable number of fuels of widely different properties over a broad temperature range and has been found to yield results that are comparable with those obtained in starting tests on engines. The method is fully described and illustrated.

Gaseous Explosions (Effect of Fuel Constitution on Rate of Rise of Pressure). (G. C. Brown and G. B. Watkins, Ind. and Eng. Chem., Vol. 19, No. 2.) (8.57/5558 U.S.A.)

Apparatus suitable for the quantitative determination of the rate of rise of pressure of gaseous explosions is described. Normal hexane, heptane and octane; benzene, toluene, xylene; methyl, ethyl and amyl alcohols, and ethyl ether were used to prepare explosive mixtures with substantially theoretical oxygen and nitrogen. These mixtures were exploded under constant initial conditions and the pressure-time curves were graphically differentiated to obtain the maximum rate of rise of pressure. Comparison of the data so obtained indicates that the rate of rise of pressure in a progressive homogeneous reaction (one in which the flame moves progressively through the explosive mixture) increases with molecular weight in the paraffin series, varies inversely with the number of methyl groups added to the benzene ring in the aromatic series and is about the same for the higher alcohols as for the corresponding paraffin hydrocarbon.

Deterioration of Mineral Oils. (R. T. Haslam and K. Frolich, Ind. and Eng. Chem., Vol. 19, No. 2.) (8.41/5557 U.S.A.)

Certain conclusions as to the mechanism of the oxidation process have been drawn for a detailed study of the oxidation by a dynamic method of highly refined mineral oil.

(1) Start of oxidation is manifested by change in colour and by increasing acidity and viscosity.

(2) The rate of oxidation increases with temperature and is about five times as rapid with pure oxygen as it is with air.

(3) A number of organic compounds have been found to act as inhibitors of the oxidation. Others have been found to act as positive catalysts or not to affect the process at all.

As a result of these and other conclusions, a scheme for the mechanism of the oxidation of mineral oils is proposed.

2 *Dopes and Detonation*

Spectrography of flames in a combustion engine. (A. Henne and G. L. Clark, Compt. Rend., 1927, 184, 26-28—abstr. in British Chem. Abstr. B, 4.3.27.) (8.514/5335 France.)

The explosion spectra of a combustion engine operating normally, with "knocking," and in the presence of anti-detonators, have been photographed at four stages of each explosion. The extent of the "knocking" is measurable by the movement of the lines of the normal spectrum towards the ultra-violet, and is greatest in the first quarter of the explosion. "Knocking" is due to a sudden liberation of energy the effect of the addition of an anti-detonator being to distribute this over a longer period of time. All the substances used (lead, tetraethyl, aniline and ethylenic hydrocarbons) produce the same spectrum as was obtained under normal circumstances. Lines due to lead appeared only in the first quarter of the explosion, indicating that the catalytic action takes place at the beginning of the reaction. The artificial "knocking" was produced by pressure.

Ionisation in Flames. (E. Marx, Ann. d. Physik, 81, 5, pp. 454-492, 18.10.26—abstr. in Sc. Abstr. A, 25.2.27.) (8.514/5330 Germany.)

This paper presents a comprehensive theory of ionisation phenomena in flame gases. From this theory of mobility, thermal ionisation and equilibrium conditions the reaction constants, recombination and dissociation coefficients, etc., can be calculated. The theory is supported by much experimental work.

"Pinking" in Internal Combustion Engines. (G. S. Maxwell, Fuel, Vol. 6, No. 3.) (8.514/5289 Great Britain.)

This article constitutes a very complete survey of the various theories put forward for the elucidation of the cause of knocking. It is stated that further experimental evidence is required on certain points. The spontaneous ignition theory, as modified by Callender's Nuclear hypothesis, seems to fit the facts better than any other suggestion. A more detailed examination of the oxygenated compounds, formed during a preliminary oxidation of paraffin hydro-carbons, is required, since the formation of organic peroxides has not yet been definitely proved.

The solution of titanous sulphate used to detect their presence is said by Engler to be a test for hydrogen peroxide, not for organic peroxides.

The latter, however, form hydrogen peroxide in the presence of moisture by autoxidation, so that they react to titanous sulphate if not carefully purified. It would appear that the action of "knock inducers" on peroxide formation must also be investigated.

Detonation. (W. A. Whatmough, Automobile Eng., March, 1927.) (8.514/5564 Great Britain.)

This paper discusses some practical considerations relating to detonation in internal combustion engines. The rate of detonation and molecular stability are dealt with. The fuel factors which individually or conjointly predispose or prevent detonation are stated to be:—

1. The compositions of the fuel.

2. The degree of sub-division of the liquid fuel.
3. The amount of admixture of air therewith.
4. The stability of the mixture at induction pipe temperature.
5. The extent to which evaporation of liquid fuel is completed within combustion chamber.

The compositions of motor fuels is also discussed.

Detonation in Internal Combustion Engines. (Letter from A. A. Egerton and S. F. Gates, Nature, Vol. 119, No. 2994, March, 1927.) (8.514/5567 Great Britain.)

It is stated that the following conclusions amongst others have been reached during an investigation on the effect of " anti-knocks " in petrol engines.

1. Anti-knocks do not influence detonation in rapid combustion mixtures.
2. They function in the initial stages of the combustion as negative catalysts.
3. Those metals which give the effective organometallic anti-knocks are found to be capable of forming higher oxides. The unstable peroxides formed in the combustion of the fuel and the metallic peroxides, are considered mutually to destroy each other. The rate of destruction of the combustion catalyst is greater than its rate of production, so that combustion is delayed. The metal atoms in a state of incipient oxidation are thus effective anti-catalysts.
4. The purely organic anti-knock, like aniline, is effective for the same reasons.
5. Both for ignition and knocking there is a condition of sensitiveness to change of reaction rate and the effect of anti-knocks is in general much the same on the two phenomena.

The views given are supported by the effect on such substances (aldehydes, organic peroxides, etc.) which permit knocking.

Dopes and Detonation. (1926 by H. L. Callender, Engineering, Feb. 4, 11 and 18, 1927.) (8.514/5553 Great Britain.)

It is noted for reference that the results of the work carried out at the Air Ministry Laboratory on dopes and detonation in internal combustion engines have been published in the Journal mentioned above. This work is, of course, well known to the D.S.R. and D.T.D. staffs concerned.

The Rating of Fuels in the Order of Detonation. (W. F. Faragher and W. H. Hubner, J. Soc. Automotive Eng., Vol. 20, No. 3, March, 1927.) (8.514/5577 U.S.A.)

This paper comprises a description of the construction of an apparatus and the development of a method of operating it in determining the rating of motor fuels in order of their detonation. A Delco-light unit, consisting of a single cylinder internal-combustion engine directly connected to a direct-current generator, was the basic outfit used but it was changed in many ways in its course of development as a testing machine. The changes made are explained in detail. The method of testing adopted for rating a motor fuel was to match it, by trial and error, with a blend of chemically pure benzine and selected straight-run Pennsylvannia fuel. Several series of experiments were made to determine what blend or blends of benzene and the standard fuel match a given fuel under widely different conditions of compression-ratio and spark-setting. The author hopes to standardise these blends later in terms of pure heptane and pure octane, as has been proposed by Dr. Graham Edgar. The results obtained in the experiments are presented graphically.

Studies of Combustion: The burning of hydrogen and carbon monoxide. (W. G. Lovell, J. D. Coleman and T. A. Boyd, Ind. and Eng. Chem., Vol. 19, No. 3.) (8.57/5573 U.S.A.)

The results of experiments described in this paper indicate that the simultaneous burning of carbon monoxide and hydrogen in a gasoline engine probably takes place according to the reactions:—

$$2H_2 + O_2$$
$$2CO + O_2$$

where the ratio of the velocity constants

$$k_{H2} : k_{CO} = 2.3.$$

Neither these reactions nor their relative rates are changed by a small increase in the compression ratio, or by the presence of a knock inducer or a knock suppressor, as long as detonation does not occur. The simultaneous combustion of two individual fuels in an engine at rates widely different for each does not appear to be in agreement with the concept of a narrow zone or flame advancing across the cylinder, within which combustion is completed.

Studies of Combustion: Determination of rate of burning by Chemical Analysis. (W. G. Lovell, J. D. Coleman and T. A. Boyd, Ind. and Eng. Chem., Vol. 19, No. 3.) (8.57/5572 U.S.A.)

As a departure from the usual methods of investigating combustion in internal combustion engines, a study has been made of the burning during its progress, from a chemical point of view. The ordinary method of examining combustion by means of the engine exhaust is subject to the disadvantages that combustion occurs so long before the exhaust stroke that the final products do not give definite information as to how it has proceeded. It is important, therefore, to sample gases from the cylinder during the actual explosion period. For this purpose, a special quick-acting, water-cooled, sampling valve has been devised, which makes it possible to follow the progress of combustion.

This new experimental method yields data particularly adapted for determining the rate of combustion. The knock is accompanied by an increase in the rate of burning of fuel, whether the detonation is caused by addition of kerosene, or by the presence of a chemical knock inducer. In the presence of tetraethly lead fuel burns at about its normal rate.

Gaseous Explosions: Probable mechanism causing detonation in the internal combustion engine. (G. C. Brown and G. B. Watkins, Ind. and Eng. Chem., Vol. 19, No. 3.) (8.514/5574 U.S.A.)

It was found that if the maximum rate of rise of pressure as determined in a progressive homogeneous reaction under constant initial conditions be divided by the autoignition temperature on the absolute temperature scale, a number is obtained which varies directly as the knocking tendency of that particular fuel in an engine, or inversely as Ricardo's "highest useful compression ratio" for that fuel.

This fact suggests rate of rise of pressure and autoignition temperature as the two factors determining the tendency of fuels to knock in an engine and autoignition of the unburned mixture adiabatically compressed against hot surfaces as the mechanism causing "fuel knock" in an internal combustion engine.

Gaseous Explosions: Rate of rise of pressure, velocity of flame travel and the detonation wave. (G. G. Brown and G. B. Watkins, Ind. and Eng. Chem., Vol. 19, No. 3.) (8.514/5575 U.S.A.)

Velocity of flame travel and rate of rise of pressure are shown to be similar and vary in the same way with changing initial conditions.

Detonating mixtures of pure liquid fuels and substantially theoretical oxygen were exploded with varying amounts of nitrogen in the constant volume bomb. The amount of nitrogen necessary to reduce the intensity of the detonation to an arbitrary standard was found to vary directly as the rate of rise of pressure as reported in the previous paper. These data lead to the conclusion that the rate of rise of pressure upon explosion of a fuel mixture is the major factor indicating the tendency of that fuel mixture to set up the detonation wave in a progressive homogeneous reaction, and that engine knock is not due to a detonation wave as recognised in progressive homogeneous explosions.

3 *Heavy Oil Engines*

The Sperry Aero Oil Engine. (Aviation, Vol. 22, No. 10, 7.3.27.) (12.81/5563 U.S.A.)

This article gives an account of a paper read by Mr. Sperry before the Metropolitan Section of the Society of Automotive Engineers. It is stated that the most highly developed light weight Diesel Engines are still too heavy for air use. Attack on the problem in the Sperry Laboratory has been largely confined to the evolution of a design which would permit the use of a higher mean effective pressure than is ordinarily used. It is proposed to obtain this by the use of a high initial supercharging pressure combined with 2-stage expansion which continues the power impulse of the expanding gases through a larger arc of the crankshaft revolution than is possible in oil engines which exhaust to the outer air. A power unit, built along aeronautical lines and capable of developing 250 h.p., is in the design stage.

4 *Carburettors*

Non-back-firing Carburettor for Aircraft Engines. (Le Genie Civil, Vol. 98, No. 26—abstracted and illustrated in Mech. Eng., Vol. 49, No. 3.) (8.53/5578 France.)

A carburettor designed by R. LeGrain is described, in which the non-back-firing feature has been worked out on the basis of the fact than an air fuel mixture containing an excessive amount of the latter does not support the propagation of a flame. It is claimed that on the engines on which this carburettor was tested a slight increase of power output was noticed, accompanied by a notable diminution of fuel consumption. The original article shows how this carburettor is installed on a 480 h.p. Renault engine.

5 *Test Engines*

Description of the N.A.C.A. Universal Test Engine and some Test Results. (M. Ware, N.A.C.A. Report No. 250.) (8.18/5286 U.S.A.)

This report describes the 5in. bore by 7in. stroke single-cylinder test engine used at the Langley Field laboratory of the National Advisory Committee for Aeronautics in laboratory research on internal combustion engine problems and presents some results of tests made therewith.

The engine is arranged for variation over wide ranges of the compression ratio and lift and timing of both inlet and exhaust valves while the engine is in operation. Provision is also made for the connection of a number of auxiliaries. These features tend to make the engine universal in character, and especially suited for the study of certain problems involving change in compression ratio, valve timing and lift.

Incidental to investigations of carburettor and fuel injection engine problems, considerable data have been obtained which indicate the effect of changes of compression ratio on friction horsepower and volumetric efficiency. From this and some other work, it appears that with a change in compression ratio from

5 to 13, the friction horse-power obtained by motoring the engine increases by about 15 per cent. The volumetric efficiency of the engine was found to remain practically unchanged between compression ratios of 5.3 and 7.3 with carburettor operation and between 9.5 and 13 with fuel injection operation.

The results of some tests are presented showing the power obtained when operating as a carburettor engine on aviation petrol at compression ratios in excess of that which will permit full throttle as a normal engine and controlling detonation by throttling the intake charge and by varying the inlet valve timing. For fixed compression ratios in these tests throttling gave the least power while variation of the inlet valve closing time, with the opening time kept fixed, gave the greatest power for the conditions tried.

6 *Ignition Systems*

(F. G. Shoemaker, J. Soc. Automotive Eng., Vol. 20, No. 3. March 1927) (8.9/5576 U.S.A.)

An account of a lecture by Mr. Shoemaker is given. He stated that the ideal ignition systems should have the following characteristics :— (a) a rugged, light and compact source of sparks; (b) flange mounting; (c) bearings large enough to allow the use of a direct splined shaft or gear drive; (d) complete enclosure of the ignition system in a metallic housing conforming to the space available on the engine; (e) secondary cables carried in substantial metallic housings, built into the cylinder-block and connected directly to the distributor housing, without flexible braid or tubing, thus providing radio shielding, mechanical protection and eliminating the fire hazard; (f) ignition drive from the propeller end of the crankshaft, to eliminate drive stresses; (g) ignition for starting direct from " running " magneto without the use of a booster magneto; (h) electrical insulation for supercharging to at least 20,000ft.; (i) a normal life without lubrication, adjustment, or cleaning greater than the time between major overhauls of the engine; (j) accessibility in the airplane for inspection of breaker and distributor; (k) easily removable and interchangeable breakers, condensers, coils and distributor parts; and (l) standardisation of the basic parts of a given make, such as main frames, coils, condensers, rotors, bearings, breakers and the like, to make it possible to use the same parts for all types of engines.

It was stated that the following may be considered as having reached the development stage :— (a) a reduction in the weight of the ignition system of from 25 to 40 per cent.; (b) an increase in the satisfactory operating speed of magnetos of at least 100 per cent.; (c) extension of the life of the magneto breaker at least five times; (d) elimination of the fire hazard; (e) direct drive without flexible coupling; (f) flange mounting; and (g) the air-gap distributor.

7 *Rotary Pumps and Gear Pumps*

Experiments with Rotary Pumps and Gear Pumps. (F. Aschner and L. Mattheus, Der Motorwagen, Vol. 30, No. 7, 10.3.27.) (8.42/5541 Germany.)

The object of the tests reported on in the present article was to determine the volumetric efficiency, or ratio of actual delivery to theoretical delivery per unit of time, of oil pumps with various values of pressure, pump speed and oil temperature, in order to ascertain the most favourable conditions for the functioning of the pump. A rotary lubrication pump from a Hispano-Suiza aero-engine, a gear pump for motor-car engines by Breuer and Co. and a gear pump by Ludwig Loewe & Co. were tested by means of a special plant (described in the article). The results of the tests are given by means of a series of curves of the volumetric efficiency both as a function of the viscosity and of the pump speed, with various values of pressure, and also of the delivery as a

function of pressure with various speeds. The following table gives the results for the most usual conditions of working, the viscosity of the oil being in all cases 6.8 Engler degrees at 50 deg. C.

Breuer Pump.				(Speed 1,500 r.p.m.)			
Pressure in atm.			0	0.5	1.0		
Vol. efficiency			80%	48%	26%		
Actual efficiency			—	2.2%	2.5%		
Loewe Pump.				(Speed 500 r.p.m.)			
Pressure in atm.			0	1	2	4	
Vol. efficiency			88%	87.4%	80%	60.6%	
Actual efficiency			—	29.4%	36%	37.6%	
Hispano Suiza Pump.				(Speed 1,000 r.p.m.)			
Pressure in atm.			0	1	2	4	7
Vol. efficiency			90%	79.2%	74.1%	65.6%	56.4%
Actual efficiency			—	18.95%	29.5%	36.0%	29.6%

AERODYNAMICS AND HYDRODYNAMICS

8 Fluid Motion

Calculation of turbulent spreading flow. (W. Tolmien (Göttingen), Z.f.A.M.u.M., Vol. 6, Dec., 1926.) (5.32/5540 Germany.)

The article deals with the mathematical investigation of the distribution of velocity in various cases of "free turbulence," *i.e.*, flows not bounded by walls, on the basis of the theory recently propounded by Prandtl (see Z. ang. Math. u. Mech. Vol. 5 (1925), p. 136) for the turbulent interchange of momentum in stationary flows. The author considers first the mixing processes occurring between a stream moving at uniform velocity and the surrounding air at rest, and then analyses how the stream spreads out into the surrounding air. Experiments show that the width of the zone in which mixing occurs increases in linear ratio with x, x being the distance from the point where the mixing commences. A method of taking into account the pressure differences and thus improving the calculations, in which constant pressure is postulated, is given and also a more complete expression for the apparent tension set up by the turbulent interchange of momentum.

Configuration of flow round a circular cylinder. (Masami Ono, Aeronautical Research Inst., Univ. of Ostend, Z.f.A.M.u.M., Feb., 1927, pp. 9-12.) (5.32/5310 Belgium.)

The author assumes that there is a Prandtl boundary layer outside which potential flow exists. Within the boundary layer the velocity is expressed tentatively as a cubic with undetermined coefficients. Proceeding along the same general lines as Prandtl and v. Karman and making various approximations a solution is obtained involving a power of the velocity of the value 1.836. The angle between the dam point and the point at which the boundary layer breaks away from the surface is found to be 106° agreeing roughly with observations and Reynolds' criterion is found to be $U_r/\nu = 2.84 \times 10^3$ which is comparable with the value for pipes.

The treatment must be regarded as empirical, and any value lies in the accuracy with which it agrees with observed facts.

Drag of an aerofoil for two-dimensional flow. (A. Fage and L. J. Jones, Proc. Roy. Soc., A. 759, 1926, pp. 592-603.) (5.32/5314 Great Britain.)

The authors continue the exploration of the velocity field referred to in Bryant and Williams' paper (on p. 12), using the expression for drag in terms of tail momentum given by G. J. Taylor (*cp.* Filon).

The distribution of normal pressure is measured and integrated over the surface and accounts for 80 per cent. of the total, the remaining 20 per cent. being assigned, by subtraction, to the vector integral of the tangential forces, which may be defined as "skin friction."

The loss of total head is integrated along the whole span for incidence of minimum drag, close to the aerofoil, and agrees with the measured drag. The integral of normal forces at the medium section and the total head losses behind the medium section are plotted between incidences $-10°$ and $+14°$, and show the same general run.

Air flow pattern in the wake of an aerofoil of finite span. (A. Fage and L. F. G. Simmons, Trans. Roy. Soc. A., 1926, pp. 303-330.) (5.32/5313 Great Britain.)

The authors explore the velocity field by direct measurement for the first time with sufficient accuracy and detail to analyse the flow in accordance with Lanchester's hypotheses and establish directly and quantitatively the physical existence of vortices trailing from the wing tips.

The relations between lift and circulation are confirmed. Numerous interesting details are confirmed—the folding of the vortex sheet, the diffusion of vorticity as the trailing cores pass down stream, the concentration near the wing tips, etc.

Aerodynamics of the Biplane. (N. K. Bose (Calcutta) with notes by L. Prandtl, Z.f.M.u.M., Feb., 1927, pp.1-9.) (5.331/5312 Germany.)

The induced velocities are found by evaluating integrals of the usual type and checked with planimetry. The influence of the curvature of the stream lines is investigated, on the lines of Kutta's investigation, and approximate expressions found for coefficients of lift and moment.

The curvature of the streamline is expressed in elliptic integrals and tabulated and given graphically.

The circulation and profile drag are determined experimentally and the coefficients of lift, drag and moment are then deduced. Comparison with direct measurement is tabulated and shows fair agreement.

The resistance of spheres. (H. Liebster, Ann. d. Physik, No. 4, 1927, pp. 541-562.) (5.32/5535 Germany.)

Cinematograph records were made from the region of resistance as the velocity to that of resistance as velocity square. The resistance was found to be a continuous function of Reynolds' number. At low speed the results agreed with the theories of Stokes and Oseen. Near a sloping wall the observations agreed with Faxen's equation better than with Lorentz and Stokes', up to 0.15cm. diameter. When Reynolds' number exceeded 0.5 irregular oscillations appeared indicating irregular instability in the tail, unlike the stable (*sic*) formation behind a cylinder.

Supposed variation of coefficient of viscosity with rate of shear. (J. W. Lewis, M.Sc., Phil. Mag., Feb., 1927, pp. 429-432.) (5.32/5532 England.)

It is shown that the experiments by K. Molin (1920) from which a variation was inferred required correction for the friction torque of the apparatus, which is sufficient to account for the departure from Stokes' linear relation.

Notes on the connection between lift and circulation. (Prof.G. I. Taylor, Trans. Roy. Soc. A., 1926, pp. 238-246.) (5.32/5315 Great Britain.)

With reference to Bryant and Williams' paper, noticed below, the author shows that it is necessary to define the contour taken for determination of the circulation, as cutting the "tail" at right angles, otherwise the circulation may

vary with the contour selected. (In an extreme case Bryant and Williams obtain a decrease of 10 per cent.) An elegant illustration is given from the Kirchoff Rayleigh problem of resistance in a perfect fluid with a wake at rest separated from the stream by steady surfaces of perfect slip. Expressions are given connecting lift and drag with the velocity field in a perfect fluid.

Flow of air around an aerofoil of infinite span. (L. W. Bryant and D. N. Williams, Trans. Roy. Soc., 1926, A. 225, A. 225, pp. 199-237.) (5.32/5316 Great Britain.)

The authors explore the velocity field round the wing and establish experimentally the existence of circulation of substantially irrotational motion outside the boundary layer and tail, and of distribution of lift, with remarkably accurate confirmation of the Lanchester-Prandtl relations. The experimental exploration of the tail affords data for further progress in setting up a physical theory of profile drag.

Certain Irrotational Motions of Viscous Liquids. (A. Rosenblatt, Comptes Rendus, 192, pp. 556-8, 4.10.26—abstr. in Sc. Abstr. A, 25.2.27.) (5.32/5337 France.)

Proves two theorems, (1) that in the irrotational motion of a viscous fluid, if the force is normal to the equipotential surfaces, then these are parallel surfaces; (2) if in addition the fluid is incompressible, then the only possible families of surfaces are parallel planes, coaxial cylinders, and concentric spheres.

Removal of Surface Layer by Suction in Fluid Flow. (J. Ackert, Z.V.D.I., Vol. 70, pp. 1153-1158, 28.8.26. Abstracted in Sc. Abstr., Vol. 30, No. 349.) (5.32/5182 Germany.)

When a fluid flows past and round an obstacle the surface layer of " dead fluid " at the rear of the obstacle may be removed by suction through apertures provided in the body itself, and the turbulence may be much reduced by this means. The results of some experiments on different forms of obstacles are described in the paper, and in an appendix a theory of the phenomenon is given in mathematical form.

9 *Pressure Distribution over Aerofoils at High Speeds*

(N. J. Briggs and H. L. Dryden, N.A.C.A. Report No. 255.) (5.421/5554 U.S.A.)

This report deals with the pressure distribution of aerofoils at high speeds. The tests were made on models of 1in. chord and comparison with the early measurements on models of 3in. chord shows that the sudden change in the lift coefficient is due to compressibility and not to a change in the Reynolds number. The Reynolds number has a large effect however on the drag coefficient.

The data observed are useful to the airscrew designer in connection with the load distribution and high speeds.

10 *Rotors*

Industrial Applications of the Flettner Rotor. (F. O. Willhoft, Mech. Eng., Vol. 49, No. 3.) (17.4/5579 U.S.A.)

The characteristics of the rotor are given and its suitability for application to wind-wheels is discussed. It is proposed to construct a 100ft. wheel with Savonius rotors to generate 183 h.p.

11 Hot Wire Instrument for Measuring Airflow

Hot Wire Instrument for measuring speed and direction of airflow. (L. F. G. Simmons and A. Bailey, Phil. Mag., 1927, pp. 81-96 and plate II.) (11.15/5317 Great Britain.)

The authors describe the construction and calibration of one, two, three and four wire instruments of this type as used in exploring the flow of air behind an aerofoil.

The necessity of calibrating periodically for "ageing" does not prevent the instrument from being more convenient for numerous and rapid readings, both of velocity and direction, than the pitot tube.

The reduced observations agree well with the pitot tube results except in the region of most intense vorticity where there may be doubt as to the relation between a variable air flow and the cooling of the hot wire or the mean pressure in the pitot tube. Elsewhere the mean readings seem to be a satisfactory measure of the time mean velocity field in so far as concerns the aerodynamical forces set up as an aerofoil—a result of fundamental importance.

Aircraft Design

12 Stresses and Accelerations in Flight

Acceleration of Aeroplanes. (J. V. Koppen and W. Huebner, Z.F.M., Vol. 17, No. 24, 18.12.26, pp. 534-7—abstr. in Nachrichten f. Luftfahrer, Vol. 8, No. 3, 20.1.27.) (5.261/5565 Germany.)

The measurements carried out by the D.V.L. of the acceleration undergone by various aeroplanes in different evolutions with the D.V.L. recording accelerometer type VV (cf. Z.F.M., Vol. 17, No. 24, December 28th, 1926) yielded much lower values, particularly in the pull out from a nose dive, than the American experiments carried out by Doolittle, in which the theoretical maxima were almost reached. Assuming the same basis for the measurements, the difference may be explained by the lower power of the elevator control, or the greater moments of inertia about the lateral axis of the German aeroplanes.

Values of Measured Accelerations.

Evolutions.	Albatros L.68	Albatros L.68a	Junkers A.20	Junkers A.35
Turn at full throttle.	2.3g, 2.7g	2.7g	2.8g	2.5g
Gliding turn.	3.8g	2.9g	3.1g	3.0g
Looping.	(2.8g, 2.8g) (3.2g, 3.8g)	(2.6g, 2.9g) (3.0g)	3.0g, 3.4g —	2.9g, 3.0g —
Rolling.	4.0g	2.7g	4.1g	3.5g
Spin with engine off.	3.0g	2.4g	3.6g	3.6g
Spin with engine on.	3.5g	2.7g	3.2g	3.5g
Gradual pull out after a nose-dive.	at 180 km/hr 2.1g	at 200 km/hr 2.4g at 250 km/hr 3.4g	at 240 km/hr 3.4g	2.3g
Sudden ditto.	3.1g (7.7)	3.6g (7.1) 4.0g (10.3)	at 250 km/hr 3.9g (9.7)	3.1g (9.7)

The figures in parentheses ( ) are the theoretical maximum values of acceleration in pulls out from nose dives.

New investigations on aeroplane stresses in flight. (M.M. Huguenard, Magnan and Planiol, Bull. Tech. du S.T. Ae., No. 3, Dec., 1926.) (5.26/5534 France.)

Chap. I., pp. 5-22. Theory, design and use of accelerometers. The relation of damping to the ratio stress displacement of the spring is fundamental. By

proper adjustment the error lies well within ± 4 per cent. of a mean curve. The sensibility of the instrument multiplied by the square of the natural frequency is taken as a figure of merit, and in four S.T.Ae. instruments this product ranged from 9,000 to 800,000 compared with figures 1,600 and 2,130 for two instruments produced by outside firms.

Chap. II., pp. 23-27. A description of a recording speed meter with a natural period of 1/40 second. The records lie within 1.1 km. per hour (± 4 per cent. of max. speed) of a mean curve. The manometer had an error of 3 per cent., combined probable error 5.5 per cent.

Chap. III., pp. 28-30. An arrangement for test recording of strains in the frame during flight (Bulletin No. 24). Special readings by fluid transmission to a recorder.

Chap. IV., pp. 31-33. Apparatus for determining flight trajectories. A cinematograph camera is mounted like a machine gun and follows the motion of an aeroplane through a ruled screen.

Chap, V., pp. 34-52. Simultaneous observations of speed acceleration and elevator movement during flying manœuvres. Three recording pins mark on the same drum the flight speed, vertical acceleration and elevator movement. Examples are given of triple records and of reduction to tabulated numerical data.

Chap. VI., pp. 53-63. Speed, acceleration and spar strain are measured simultaneously. Approximately linear relations between acceleration and spar strains are given graphically.

Chap. VII. An application of the method of Chap. IV. to two aeroplanes, one for speed (200 km. per hr.) the other looping the loop. A large number of reproductions of film exposures are given, showing the variable positions of the aeroplane on the ruled screen alternating with chronographic records of the time.

13 Structures

Determination of the best sectional dimensions of a hollow rectangular built up spar. (A. v. Baranoff, Z.f.M.u.M., Feb., 1927, pp. 81-83.) (5.21/5543 Germany.)

Adopting the views and methods of Newlin and Trayer, N.A.C.A. Technical Reports No. 180, 181, 178, graphical determinations in families of curves determine the proportion of flange widths and depths, for the development of maximum resistance against both end loading and bending, taking into account the test qualities of the timber used. With increasing tensile strength of the timber, the ratio of cross section area of pressure flange to tension flange increases, while the flanges become thinner in proportion to girder depth. On the contrary with increasing compressional strength the ratio of flange to girder depth increases and the ratio of area of compression to tension flange decreases.

14 Airscrews

Preparing laminations for airscrews construction. (Otto Steinitz, Z.f.M.u.M., pp. 93-95, Feb., 1927.) (5.462/5533 Germany.)

A number of workshop methods and tests are given.

Airscrews for high flying aeroplane. (Paper at a discussion of the Wiss. Gesell. fur Luftfahrt, Z.f.M.u.M., Feb., 1927, pp. 83-93.) (5.41/5544 Germany.)

The author dismisses as impracticable for heavily loaded commercial vehicles a current proposal to set up flying routes in the regions above the troposphere (10 km. and upwards) with a view to developing higher speeds in the rarer air (less than one quarter the density at ground level), but considers the particular problem of designing airscrews for high flying aeroplanes. He gives nomographs for a range of 10 atmospheres to 1/100 atmosphere and concludes that no special difficulties of design and construction arise.

Balsa Wood Airscrew. (Aviation, 7.2.27, p. 271.) (10.31/5283 U.S.A.)

An airscrew is illustrated having a diameter of 17ft. 6in. The material Balsa Wood, is stated to weigh only $\frac{1}{8}$ as much as birch or oak. Method of constructing airscrew is described.

15 Brakes for Aircraft

(U.S. Air Services, Feb., 1927.) (5.55/5552 U.S.A.)

Early in 1925 McCook Field undertook the study and development of brakes for the Douglas D.T.1 for the purpose of increasing ground control. Disc type brakes were used; a duralumin disc sufficiently conical to lie parallel with the spokes was rivetted to the rim of the wheel. The disc was extended to the centre where it rested on the hub of the wheel. Outside this was the lined breaking disc.

These brakes functioned satisfactorily and are still in regular service. The run of the aircraft after landing was reduced from about 1000ft. to about 350ft. by the use of these brakes and with no noticeable tendency to nose over.

The next brakes developed were the separately controlled hydraulic brakes for the P.1 aircraft. It is understood that these brakes are also in satisfactory operation.

16 Wing Design

Precision of wing sections and consequent aerodynamic effects. (F. Rizzo, N.A.C.A. Tech. Note No. 255.) (5.31/5178 U.S.A.)

This investigation was carried out by the N.A.C.A. to determine the precision of wing sections of wood-fabric construction used on a number of airplanes. It was found that all wind sections deviated more or less from their respective prototypes. The mean thickness of the section was computed for those wings with a noticeable sag. The aerodynamic effects resulting from consideration of thickness variation are then estimated from existing empirical information. The rib, sag and specified measurements of fourteen sections investigated are given.

Flap gear for Aeroplanes. (A. Hessell Tiltman, Autom. Eng., Feb., 1927.) (5.313/5278 Great Britain.)

This article, which is well illustrated, contains a summary of the work done on variable camber wings, but particular attention is paid to one particular design of automatic flap gear.

17 Take-off and Landing Characteristics

Comparison of the take-off and landing characteristics of a number of service airplanes. (T. Carroll, N.A.C.A. Report No. 249.) (7.17/5165 U.S.A.)

This investigation is a continuation of N.A.C.A. Report No. 154, in which the take-off and landing characteristics of the J.N./4h were reported upon. The present report gives similar results for a number of U.S.A. service aircraft. The results include the air speed, ground speed, ground run distance, acceleration, and position of all controls throughout the take-off and landing operations for each aircraft.

18 Fire Prevention

Fire Prevention and Extinguishing Apparatus for use with Petrol Tanks. (L. Ingram, E.P. 262697, 16.12.26.) (16.12/5551 Great Britain.)

The invention comprises a glass receptacle containing a chemical fire extinguisher which is placed across the top of the petrol tank, and which can be broken by the impact of a plunger.

The protection of aircraft against fire risks. (J. A. Lefrance, La Nature, 1.3.27.) (16.12/5529 France.)

A general article on fire risks and their prevention. The author enumerates the best means of fire prevention; the use of powerful extinguishers, the mounting of the tanks as far as possible from the engine, the use of metal, more especially steel, in aircraft construction and considers that the best means of reducing fires in aircraft is the use of non-inflammable fuels such as Ketol or Makhonine.

INSTRUMENTS

19 *Wireless*

Secret Communication Systems. (J. Jammet, Onde Elec., 5, pp. 365-77. Abstracted in Sc. Abstr., Vol. 30, No. 349.) (13.1/5183 France.)

In this paper the author presents a system for ensuring secrecy of Morse messages transmitted by line or radio. The outstanding feature is the extreme simplicity of the system both in principle and mechanism. The underlying principle is the use of a key that is not in any way periodic and hence practically impossible to solve. The system involves the use of three relays which will be termed A, B and C. The C relay has its tongue and marking contact connected either to line or to the radio transmitter key through a battery in the normal way. One end of the operating coil of this relay is connected directly to the tongue of relay B, the other to the tongue of relay A through a battery. The spacing and marking contacts of relays A and B are connected together. The tongue of relay A is operated by the message to be transmitted. The tongue of relay B is operated by any arbitrary message. It will be seen that a dot in the real message may appear on the line as a dot, a portion of a long dash or a space, depending on the form of the message operating relay B. Thus quite unintelligible signals are sent to line. At the receiving end there is an exactly similar arrangement of relays, A′, say, being operated by the line currents, B′ by the same arbitrary message as B (it must, of course, be in exact synchronism with B), while the relay C′ operates an inker or other recorder and records the original message as fed into relay A. The author gives details of the methods adopted to secure the necessary synchronism and discusses the operation of the system in general.

Recent Developments in Short-Wave Wireless Telegraphy. (H. Rukop, Z.f. Hochfrequenztech., 28, 2, pp. 41-50, 1926. Abstracted in Sc. Abstr., Vol. 30, No. 349.) (13.7/5184 Germany.)

A full account is given of the results of an extensive series of researches relative to wireless transmission between Nauen on the one hand and Buenos Aires, Bandoeng and Osaka on the other, with waves of length between 70 and 13 metres. The results obtained show that the optimum wave-length lies between 16 and 28 metres. Generally speaking, the night hours have given good intercommunication, though there were also cases of good communication throughout the twenty-four hours by using two wave-lengths. The apparatus used for transmission of the short waves employed is described with illustrations, and the theory of propagation of short waves is put forward and discussed.

Propagation of Short Waves. (R. Mesny, Onde Elec. 5, pp. 434-459, Disc. 459-463, Sept., 1926—abstr. in Sc. Abstr. A., 25.2.27.) (13.7/5328 France.)

After outlining the phenomena which characterise the propagation of short waves, such as great range, zones of silence, influence of night and of the seasons, the author discusses the theories which have been put forward to explain the effects observed. The hypotheses on which physicists rely for justifying the existence of a conducting layer in the upper atmosphere are discussed, and this

is followed by a general treatment of the propagation of waves in an ionised medium, showing how reflection and refraction towards the earth arise. From the general theory an approximate explanation of the observed phenomena is deduced. In conclusion, experiments to test the validity of the theories put forward are dealt with, and the differences which still exist between observed effects and the consequences of the theories advanced to explain them are pointed out.

Piezo-Electric crystals for high frequencies. (A. Meissner, Jahrbuch der drahtlosen Telegraphie u. Telefonie—Z.f. Hochfrequenztechnik, Vol. 9, No. 1, Jan., 1927.) (13.21/5530 Germany.)

This article includes the description of a method for taking the resonance curve of quartz and of a new process for wave rectification. The crystal is connected in series with a helium valve and on resonance being established passes the current to the latter. The quartz crystal is further examined from the point of view of its capacity to produce oscillations, in particular for short-wave transmitters. Investigation of the symmetrical forces producing moments of rotation in a crystal with maximum length along the optical axis led to the construction of a small motor in which rotation is imparted to a crystal by the application of a high frequency current. As a result of the investigations the author was able to establish the relations between the optical and mechanical directions of rotation of a flat crystal, finding that these coincide.

Measurements in the field of a staff-shaped aerial excited with fundamental wavelength and with harmonics. (Ludwig Bergman, Ann. d. Physik, No. 4, 1927, pp. 504-540.) (13.1/5530 Germany.)

A valve transmitter excited undamped oscillations of 1.72 m. wave-length and set up even and odd harmonics in a staff-shaped aerial, which were measured up to the sixth harmonic.

Each frequency had its own direction of transmission in good agreement with Abraham's equations, for direction but not for strength. The possibility of determining the oblique direction emitted is stated to be of practical importance in propagating waves of short length.

A relation between the meteorological state and the propagation of electromagnetic waves. (Records of the Prussian Aeronautical Observatory, Lindenberg, Vol. 15, 1926, pp. 292-296.) (13.1/5539 Germany.)

The Power of Propagation of Short Waves. (Pederson, Berlingske Tidende, 5.3.27.) (13.7/5555 Denmark.)

This article gives an account of a lecture on recent experiments on the power of propagation of wireless waves, and particularly short waves. It is a curious phenomenon that waves of a given length travel perfectly during the day and not at all at night, whilst the opposite is true for waves of another length.

The article discusses the connection between transmission of wireless waves and the conditions of the upper air.

20 Photography

K.8 *Automatic Recording Aerial Camera.* (Aviation, 28.2.27.) (14/21/5333 U.S.A.)

This camera is officially known as the Fairchild Military Fully Automatic Recording Aerial Camera, Type K.8. It is of the single lens type, fully automatic in its functioning and can be equipped to accommodate lens of focal lengths ranging from 21 c.m. to 50 c.m. On the outside edge of the 7in. × 9in. negative

is automatically recorded the hour, minute and second the photograph was taken, the inclination of the camera, the altitude, the number of exposures, focal length of the lens, and the day, month and year.

Photography through mist. (Chem. Zentr., 1927, 98 (1) 1110.) (14.5/5331 Germany.)

Photographs taken by W. H. Wright (Lick. Sternwart) on plates sensitised to ultra-red light (max. 770 to 820 $m\mu$) with Kryptocyanin and Neocyanin respectively are given. The penetrative power of ultra-red light through mist permits the taking of objects at 200 km. range which remain hidden to unsensitised plates as well as to the naked and and aided eye. Photographs of Mars are made possible through several km. of thick Martian atmosphere. The importance of ultra-red sensitisation to the film industry is mentioned; by its aid it is possible during daytime and with the normal exposures to take "night photographs" since the sky is rendered black, the surroundings appearing bright by contrast.

Air Survey. (Am. Soc. C.E., 52, 367-395—abstracted in Eng. Abstr., Jan., 1927.) (14.1/5167 U.S.A.)

The author states that in order to convert the data of photographs to a uniform scale a number of obstacles and limitations must be overcome. Some of these are inherent in all photographs, some are characteristic of photographic materials and some are due to difficulties in practical operation. The most troublesome, however, are those involving mechanical obstacles. He considers these limitations at length and discusses the mosaic with its advantage of speed and disadvantage of lack of uniform scale. He deals with field operations, flying, photographing, ground control and office work, and describes the measuring stereoscope and the method by which each plate is "horizontalised" after the tilt has been determined. In a test case, compared with an instrumental ground survey, the photographic map coincided very satisfactorily with the instrumental survey. Aeroplane contours were determined within an error of $-2\frac{1}{2}$ ft.

The Hugershoff "Aerocartograph." (E. R. Krahmer, Luftfahrt, Vol. 31, No. 5, 5.3.27.) (14.31/5569 Germany.)

This article on air surveying in general and on the aerocartograph in particular gives the following information on this new instrument which has been evolved by Dr. Hugershoff to meet the demand for a portable instrument. It weighs 200 kg. (441 lbs.) and its dimensions being 80 × 111 × 170 cm. (2 ft. 7 in. × 3 ft. 8 in. × 5 ft. 7 in.), it can be transported by motor lorry without difficulty. The "aerocartograph" is built on the same principles as Dr. Hugershoff's well-known "autocartograph" and can be used to plot maps from oblique or vertical photographs taken from an aircraft, or from photographs taken on the ground. It is constructed for focal distances of 12 to 30 cm. and square or rectangular plates with wides measuring from 6 to 18 cm. It can be worked by one operator. The aerocartograph is provided with a special system which does away with the necessity for triangulation in areas with landmarks 50 km. and more apart and thus is particularly suitable for surveys in undeveloped countries.

21 *Lighting Equipment*

Navigation Lighting Equipment. (Flight, 10.2.27.) (6.64/5279 Great Britain.)

The article describes and illustrates a new series of navigation lamps constructed by Vickers, Ltd. A saving of weight of 57.5 per cent. is stated to have been obtained and a reduction in frontal area of 9 per cent. accompanies the

saving in weight. The generating equipment has also been redesigned with a saving of weight of 4½ lbs. The weights are airscrew, 6 ozs.; generator and mounting, 11 lbs. 6½ ozs.; combined voltage control regulator and output, 3 lbs. ½ oz.; voltmeter, 9 ozs.; special 340 amp. accumulator, 40 lbs. empty.

Aircraft lights and ground lights. (M. Marsat, Revue Generale de l'Electricite, No. 23, Vol. 10, 4.12.26.) (6.64/5176 France.)

This is a summarised report of a paper published in the "Bulletin de la Ste. Francaise des Electriciens" for August, 1926. It is mostly a comparison between lights of the lens and reflector type, the author being an emphatic partisan of the latter. The question of range is dealt with, the author pointing out that as the range of a light varies with the duration of a flash, the light periods of a flashing light should be all of the same duration, the required characteristic being given by varying the durations of the eclipse. He also mentions the recent discovery that the intensity of a beam of light does not decrease uniformly with distance over all the extent of the beam, the decrease in intensity being much greater at the periphery than at the centre.

It is stated that a large number of air lights of medium range is preferable to a smaller number of powerful lights placed further apart, as was proved in the tests on the Paris-London airway; and also that for A.A. work wide angle lights often give good results where more powerful lights throwing a narrow beam are inefficient.

Aerodrome Lighting. (O. Werner, Aviation, 28.2.27.) (20.5/5332 U.S.A.)

The article includes an account of the revolving beacon, aerodrome boundary lights, marker lights giving the most favourable points of approach, lights illuminating the wind cone, obstruction lights and aerodrome flood lights.

22 *Accumulators*

Pouchain accumulators. (C. Palestrino, Electtrotecnica, 13, pp. 617-619, 25.9.26. Abstr. in Sci. Abstr. B, Vol. 30, No. 349, 25.1.27.) (21.1/5284 Italy.)

Gives the results of tests of Pouchain accumulators at high rates of discharge. It is found that these cells will withstand without damage a discharge at four times the rate possible in the case of a lead accumulator, the comparison being made on the basis of watts per kg.

23 *Calibration of Altimeters*

Tables for calibrating altimeters and computing altitudes based on the standard atmosphere. (W. G. Brombacher, N.A.C.A. Report No. 246.) (6.333/5175 U.S.A.)

The title is self-explanatory. The tables necessary for the use of the standard atmosphere in calibrating altimeters and in computing altitudes, form the principal part of this report. In Table I. are given the standard altitudes at pressure intervals of 0.1 millimeter of mercury in the range 87 to 200 millimeters of mercury and at intervals of 0.2 millimeter of mercury in the range 200 to 790 millimeters of mercury. In Table II. standard altitudes are given at intervals of 0.01 inch of mercury in the range 3.4 to 31.09 inches of mercury. In Table III. are given the pressure in inches and millimeters of mercury, the temperature, the mean temperature, and the corresponding isothermal altitude at every 500-foot interval of standard altitude in the range −1,000 to +50,000 feet. Temperature corrections for use in computing altitudes from observed pressures and temperatures are also given. An example of the computation of actual altitude from the necessary observations of pressure and temperature is included.

24 Suction Nozzles

Investigations of the flow in front of suction nozzles. (Dipl. Ing. Schulz, Z.V.D.I., Vol. 70, No. 41, 9.10.26.) (6.381/5347 Germany.)

These tests were carried out with suction nozzles of various forms (cylindrical and converging with rectangular prismatic mouth-piece and with sudden (sharp angled) or gradual (curved) transition between the cylindrical and expanded portions) having cross-sectional areas varying between 0.287 and 0.014 sq. m. As the direction of the flow was always unknown and considerable variations in the pressure and velocity values were to be expected in the field of measurement, the hot-wire method advocated by Zinn was used. Pressure and velocity were measured for various conditions of flow in vertical, horizontal and diagonal planes that always contained the axis of the nozzle which was horizontal in all the tests. The results of the measurements agree comparatively well with the flow and velocity curves established from the theory of potential flow for two characteristic nozzles. At the periphery of the nozzle, owing to friction, the flow separates off the wall, dead water areas being formed. There is a nucleus of turbulent motion at the centre of the flow at the mouth, with comparatively steady flow between the nucleus and the disturbed region at the periphery. Owing to the vortices in the nucleus, an increase in the low pressure occurs, so that, at this point, it differs considerably from that calculated by Bernouilli's law of similarity for the flow in front of geometrically similar nozzles.

Other tests were carried out with one cylindrical and two converging nozzles to determine the most efficient form for the transformation of pressure into velocity with the smallest expenditure of energy. The converging nozzles were found to be by far the better as regards quantity delivered whilst for the production of high velocities in front of the nozzle (suction efficiency), the converging nozzle with the sharp angle transition is the only one giving advantageous results.

Materials

25 Light Alloys

The corrosion of Magnesium and of the Magnesium Aluminium Alloys containing Manganese. (J. A. Boyer, N.A.C.A. Report No. 248.) (10.27/5580 U.S.A.)

The extensive use of Magnesium and its alloys in aircraft has been seriously handicapped by the uncertainties surrounding their resistance to corrosion. The report discusses the general nature of the corrosive action and metallographic study of corrosion.

It is concluded that (1) pure magnesium of ordinary ingot grade is quite resistant to corrosion by salt water, (2) the addition of aluminium increases the rate of corrosion, but the presence of a small amount of manganese counteracts to a large extent the effect of the added aluminium, (3) a critical amount of manganese is necessary to inhibit the corrosion of the aluminium alloys; at least 0.3 per cent. manganese should be present in the 4 per cent. aluminium alloy. Alloys which do not contain the critical amount of manganese corrode until completely disintegrated.

Several other conclusions are reached.

Lautal. (Fuss, Z. Metallk., 1927, 19, 19-21—abstr. in Brit. Chem. Abstr. B, 11.3.27.) (10.21/5581 U.S.A.)

Lautal (4 per cent. Cu, 2 per cent. Si, remainder commercial Al) is readily forged at 400-500° and subsequently hardened by ageing at 120-130°. The sand-cast alloy has a tensile strength of 12-20 kg./mm.^{2}, an elongation of 4 per cent., and a Brinell hardness of 55-60; after ageing the corresponding values are

16-26 kg./mm.^{2}, 4 per cent. and 65-70. The chill-cast alloy has a tensile strength of 15-25 kg./mm.^{2}, an elongation of 10 per cent., and a hardness of 66-80; after ageing these values become 20-30 kg./mm.^{2}, up to 10 per cent., and 90-110 respectively. The alloy has been used satisfactorily for the framework of aeroplanes and motor boats and for the construction of the rotors of Flettner's rotor ship.

The Brinell Hardness of Lautal between 20-500 Deg. C. (H. Kohrig, Zeit. f. Metallkunde, No. 10, Vol. 8, Oct., 1926.) (10.21/5169 Germany.)

In this article the author reports on tests carried out on test-pieces of rolled sheet 6mm. thick and hardened to the normal value. The test-pieces were heated up to 250 deg. C. in a tar oil bath and for the range between 250 deg. C. and 500 deg. C. in a melt of potassium and sodium nitrate. Balls of 2.5 and 5mm. diameter were used. The load was the same in all the tests, namely, 62.5kg. Two series of tests were carried out, one with the test piece at the temperature indicated for the test and the other after the test-pieces and cooled down from the given temperature in air. The results are given in the following table :—

	Test-pieces Hot.				Same Test-pieces Cold.	
Temp. (deg. C.).	Diam. of 2.5 mm. ball.	Imprint 5 mm. ball.	Brinell No. (2.5 mm. ball).	Brinell No. (5 mm. ball).	Dia. of imprint (2.5 mm. ball).	Brinell No (2.5 mm. ball).
20	0.815	—	116.5	—	—	—
50	0.82	—	115	—	0.815	116.5
75	0.82	—	115	—	0.813	117
100	0.843	—	109.5	—	0.815	116.5
125	0.87	—	102	—	0.817	116
150	0.92	—	90.8	—	0.82	115
200	1.08	1.12	64.8	62.2	0.845	108.5
250	—	1.335	—	44.0	0.883	98
275	—	1.5	—	34.8	0.91	92
300	1.63	1.72	26.3	26.0	0.96	83.4
350	—	2.16	—	16.2	1.03	71.6
400	—	2.86	—	8.8	1.095	63
450	—	3.23	—	5.7	1.087	64
500	—	3.67	—	5.0	1.06	67.4

Some new aluminium alloys. (K. L. Meissner, Z.V.D. 1, Vol. 6, No. 52, 29.12.26—abstracted in Nachrichten fuer Luftfahrer, Vol. 8, No. 3, 20.1.27.) (10.21/5568 Germany.)

Montegal.—The principal components of the alloy are magnesium silicide and calcium silicide in very small quantities. Good weathering properties.

Constructal 2.—Strength properties similar to duralumin, due to relatively small quantities of inter-metallic combinations of Mg_2 Si Cu and Ti. Easily worked up cold, high resistance to corrosion.

Constructal 8.—In addition to small quantities of components of high melting point, contains an inter-metallic combination of Mg Zn_2 which imparts particularly high strength values to the alloy. By appropriate combinations of mechanical and heat treatment these values may reach 60 kg/sq. mm.

K.S. Seawater Alloy.—Casting alloy, contains Mg, Mn and Sb. The resistance to seawater is mainly due to the protective action of the Sb, which, with the salts in the water forms an adhering layer of antimony oxychloride.

Strasser Casting Alloys.—Cast in various degrees of hardness according to the amount of the alloying components (from 3 to 8 per cent.) These alloys have

the peculiar property of hardening by ordinary ageing without special heat treatment.

PROPERTIES OF THE ALLOYS.

Alloy.	Maker.	Tensile strength kg./sq. mm.	Elongation per cent.	Yield point kg./sq. mm.
Montegal.	Berg A.G. Werdohl i.W.	30 to 35	12 to 16	—
Constructal 2.		Same as duralumin.		
Constructal 8.		48 to 53 (up to 60)	9 to 14 (5 to 7)	37 to 39
Aluminium Copper Alloy.	Aluminium Co. of America.	37.8	15	

Constructal. (W. Sander, Z. Metallk., 1927, 19, 21—abstr. in Brit. Chem. Abstr., B., 11.3.27.) (10.21/5562 Germany.)

Constructal is an aluminium alloy containing only 3 per cent. of alloying elements, chiefly zinc, and, after ageing, has a tensile strength of 40 kg/mm², an elongation of 22 per cent., and a Brinell hardness of 118. By modifying the ageing conditions a tensile strength of 52 kg/mm² with an elongation of 10-12 per cent., an elongation of 20-28 per cent. with a tensile strength of 36-38 kg/mm², may be obtained. Another form of the alloy containing a somewhat larger proportion of other elements has a tensile strength of 60 kg/mm², and a much better resistance to corrosion than ordinary aluminium, owing to the alloying elements being entirely in solid solution.

Scleron and Aeron. (E. Scheuer, Z. Metallk., 1927, 19, 16-19—abstr. in Brit. Chem. Abstr., B., 11.3.27.) (10.21/5561 Germany.)

Scleron is an aluminium alloy resembling duralumin, but containing lithium in place of all or part of the magnesium; it is characterised by a high resistance to change of shape, by a high tensile strength (40-50 kg/mm²) and hardness, and by a good elastic limit (20 kg/mm²) and limit of proportionality 30 kg/mm².

Aeron, on the other hand, is a copper-aluminium alloy which can be improved by ageing, and is characterised by great pliability, having an elongation of 18-25 per cent., with a reduction of area of 30-40 per cent., combined with a tensile strength of 36 kg/mm², an elastic limit of 12 kg/mm², and a limit of proportionality of 20-24 kg/mm². Scleron thus resembles a mild steel and aeron wrought iron in mechanical properties. The sp. gr. of the alloys are 2.95 and 2.8 respectively, the coefficients of expansion 2.6×10^{-5} and 2.36×10^{-5}, the thermal conductivities 0.24 and 0.36, and the electrical conductivities 16.7 and 24. The heat treatment of scleron comprises quenching from 480° and ageing at the ordinary temperature for a few days. The greatest hardness of aeron is obtained by ageing at 100-120° after quenching at 500°; both alloys are completely annealed again by heating at 300-350°. Aeron is a little more resistant to attack by sea water when aged below 100°, and much less when aged at higher temperatures than is commercial aluminium.

Solution of Aluminium and its alloys in acids. (Inspector General Grard Bull. Techn. du S.T.Ae., No. 37, pp. 1-51.) (10.21/5537 France.)

The rate of solution of aluminium in hydrochloric acid is studied in relation to the effects of grain, impurities, treatment, etc., in Chaps. I.-V. In Chap VI. the rate of solution in caustic soda is studied. An electro-chemical theory is developed and applies to both acid and alkali solvents.

Protective coatings for duralumin and similar light weight alloys for exposed construction. (H. A. Gardner, Am. Paint and Varnish Manufrs. Assoc. Circ. No. 296, 1-26 (1927)—abstr. in Chem. Abstr., Vol. 21, No. 4, 20.2.27.) (10.27/5340 U.S.A.)

Contrary to usual thought and practice, tests prove that basic pigments, such as red lead and ZnO, are highly suitable on AI and other light alloys. Results are given of the protective action in exposure tests of many varieties of coatings including lacquers. Long linseed oil or tung oil varnishes with AI or C pigments are well suited for AI alloy protection.

26 *Steels*

Investigations of Martensite. (Report No. 61 of the Verein deutscher Eisenhuttenleute reviewed—Z.V.D.I. No. 5, Vol. 71, 29.1.27.) (10.11/5528 Germany.)

The report under review deals with the investigations carried out by Hanemann and Schrader with a view to finding a new solution for the old problem of the processes of hardening in steel. From critical study of the results of research on martensite relative to structure, elongation, critical points in decalescence and recalescence and X-ray investigations the authors came to the conclusion that the prevailing views on the formation and structure of martensite were improbable. Their own conclusions are to the effect that martensite is not α iron but occurs at a temperature between 200 and 400 deg. C. when a temperature colour and a change in length become apparent. The reviewer explains how Hanemann and Schrader built up the $\xi\eta$ hypothesis which they have been able to prove by examination of the hardened structure of a number of steels.

Effect of Velocity on Corrosion of Steel under Water. (R. P. Russell, E. L. Chappell and A. White, Ind. and Eng. Chem., Vol. 19, No. 1.) (10.15/5550 U.S.A.)

The paper discusses the effect on the rate of corrosion of the velocity of liquid flowing past submerged metal surfaces. Data given in the article show that, when cleaned or polished steel is corroded under water for short periods, the corrosion may be high at low velocities and becomes less with further increase in velocity. When steel is rusted previously, however, the corrosion at velocities up to 4ft. a second is greater than the corrosion observed at very low velocities.

27 *Glass*

Some recent types of absorbent glass. (G. Jaeckel, Z.f. Tech. Physik, pp. 301-304, 1926—abstracted in Z.f. Instrumentenkunde, Vol. 47, No. 2, Feb., 1927.) (10.51/5566 Germany.)

In this article several types of glass transparent to ultra-violet rays are described, some of these being also transparent to the visible spectral range (crown glass transparent to ultra-violet rays) and some reducing more or less the intensity of the visible spectrum (blue glass, transparent to ultra-violet rays, reducing the long-wave portion of the spectrum up to about 440mμ and black glass transparent to ultra-violet rays and absorbing the entire visible spectrum). The Sendling or black glass is tinted with nickel oxide, and in thin sheets is transparent to extreme red and extreme violet rays. With a thickness of 4mm. it is practically opaque to visible light, but is as transparent as crown glass to ultra-violet rays. It is very useful for examining very weak fluorescences which have also been examined by this means on absorbent glasses. Whilst cerium glass shows a luminous blue fluorescence, and vanadium glass a greenish brown fluorescence, yellow (cadmium sulphide) glasses show light yellow, yellow-orange and deep red fluorescences, according to the position of the limit of absorption

for short-waves. These yellow glasses derive their fluorescence characteristics from being annealed at 640 to 720°, the colour deepening with the increase of temperature and duration of the anneal. Unannealed yellow glass shows no fluorescence, thus indicating that the fluorescence and absorbent properties of these glasses are only due to annealing and the consequent formation of colloids in the glass. By annealing in a furnace with uneven distribution of temperature, it is possible to anneal a yellow glass to a "wedge" of graduated shades. The movement of the limit of absorption and of the colour of the fluorescence towards the long-wave region is due to a growth of the colouring colloid. Accordingly a "yellow wedge" shows a notable variation not only of yellow colouring, but also of the colour of the fluorescence, along its length. The author deals further with the relationship between the absorption limit, colour of fluorescence and growth of the colloid.

Physical Properties of Glasses—Relationship to Chemical Composition and Mode of Preparation. (W. E. S. Turner, J. Chem. Soc., pp. 2091-2116, Aug., 1926—abstr. in Sc. Abstr. A., 25.2.27.) (10.51/5336 Great Britain.)

A review of the present state of knowledge with regard to glasses, with special reference to recent work. The effect of the component oxides or elements on the physical properties is discussed. Special reference is made, amongst properties of the constitutive type, to viscosity, annealing temperature, electric conductivity, and resistance to water and chemical reagents. Amongst properties of the additive type, special consideration is given to thermal expansion, density, refractive index and dispersion. The importance of these data in the commercial preparation of glasses designed for specialised uses (*e.g.*, optical glasses of specified refractive index and glasses which furnish resistance to the action of water and acids and which show a high degree of immunity towards sudden changes of temperature) is stressed.

28 Dopes and Paints

"Fireproof" paint. (F. S. Vivas, U.S. Patent No. 1,612,671, 28.12.26—abstr. in Chem. Abstr., Vol. 21, No. 4, 20.2.27.) (10.45/5339 U.S.A.)

A paint adapted for use on wood, paper or other materials is formed from a drying oil, Zn white, $PbSO_4$, $PbCO_3$, finely divided inert filling material such as SiO_2 or kaolin, borax, K alum, H_3BO_3, Na tungstate and a thinner. U.S. 1,612,672 specifies a paint formed of oil, ester gum, thinner, pigments, SiO_2 and Zn stearate. U.S. 1,612,673 specified a fire-resisting varnish formed with drying oil, varnish gum, glycerol, lime Co acetate or Pb acetate, a thinner, borax, H_3BO_3, Na tungstate and perchloroethane.

Nitrocellulose Lacquer Films. (G. W. Rundle and W. C. Norris, Proc. Amer. Soc. Testing Materials, 1926, 26, Part 2, 546-555—abstr. in B.C.I.R.A. Information Bureau.) (10.42/5560 U.S.A.)

Films for stress-strain measurements are easily prepared by flowing them on amalgamated tinned sheet-iron panels, setting them up at an angle of 15° to the vertical and allowing the excess material to flow off. The influence of thickness of film, humidity, temperature and variations in lacquer composition on the results of stress-strain measurements are discussed.

29 Comparative Hardness of Metals

Comparative Hardness of Certain Metallic Elements. (Letter from A. Mallock in Nature, 19.2.27.) (10.62/5282 Great Britain.)

Referring to a description of a method of determining hardness given in Nature of January 23rd, 1926, a table is given of 24 metallic elements arranged in order of hardness.

Hardness stated in tons/square inch.

Metal.	Hardness.	Remarks.
1. Iridium.	240	M.
2. Molybdenum.	158	M. Wire.
3. Tungsten.	144	Thin plate, slaty fracture.
4. Rhodium.	128	M. Wire.
5. Nickel.	112	M. Wire.
6. Chronium.	109	Cast. Crystalline aggregate.
7. Cobalt.	99	M. Cast.
8. Titanium.	77	Plate, slaty fracture. Brittle.
9. Manganese.	60	Cast. Crystalline aggregate.
10. Iron.	56	M. From ingot made by Merriot process. Pure.
11. Copper.	50	M. Wire.
12. Aluminium.	29	M. Wire.
13. Vanadium.	28	Crystalline aggregate. Brittle.
14. Palladium.	28	M. Wire.
15. Silver.	25	M. Cast.
16. Magnesium.	22	M. Cast.
17. Zinc.	21	M. Cast.
18. Gold.	20	M. Cast.
19. Calcium.	17·5	Crystalline aggregate. Brittle.
20. Cadmium.	12	M. Cast.
21. Bismuth.	8	Large, crystal.
22. Tin.	7	M. Cast.
23. Lead.	3	M. Cast.
24. Thallium.		

30 *Welding and Soldering*

Fusion Joining in Aircraft Construction. (American Machinist, 15.2.27, p. 954.) (10.22/5290 U.S.A.)

The adaptability of arc and gas welding is referred to. Alloy steels are discussed, and it is stated that chrome-vanadium steel may be brazed to chrome-molybdenum tube without difficulty. Nickel-steel bar and tube is stated to be difficult owing to cracking. Aluminium welding is also referred to, but it is only employed to a minor extent.

31 *Internal Structure of Metals*

Direct stereoscopic optical investigation of the internal structure of bodies, especially crystals. (Dr. H. Herbst, of Jena, Zeit. f. Instrumentenkunde, Sept., 1926.) (10.63/5162 Germany.)

This article describes a method of rendering the molecular structure of crystals and similar bodies directly visible by means of the "Atom-miscroscope," in which the action of Rontgen rays or other rays of even shorter wave-length is combined with that of ordinary or ultra-violet light rays in such a way that the visible or ultra-violet rays simultaneously or successively follow the same or the inverse path as the Rontgen rays deflected or bent by the object, the visible or ultra-violet rays being then collected in the usual way by means of glass or quartz lenses or by a system of prisms as in the binocular microscope, so as to give a binocular stereoscopic image, allowing the internal structure of the body to be viewed directly in three dimensions. The path of the deflected Rontgen rays can be marked in the usual way by a photographic plate or screen, and the stereoscopic image can also be measured stereoscopically.

The essential difference between this "Atom-microscope" and the ordinary or ultra-microscope is that the latter only permits of viewing the external shape of

the object, whilst the former actually renders visible the internal structure and the arrangement in space of its components, the object being illuminated from two different sides by a bundle of rays of short wave-length, and the resulting "shadows" or "reflected" or "deflected" rays caught on two screens or photographic plates which are viewed through a stereoscope.

32 *Selenium in Rubber Compounds*

(C. R. Boggs and E. M. Follansbee, Trans. Inst. Rubber Ind., 1926, 2, 272-304—abstr. in British Chem. Abstr. B, 4.3.27.) (10.52/5338 England.)

A review of the uses of selenium in rubber compounding. Selenium can be used as a vulcanising agent or to accelerate vulcanisation by sulphur, the latter effect being attributed to the formation of selenium sulphide. The enhanced rigidity and abrasion resistance of tyre tread "compounds" vulcanised with a sulphur and selenium in the presence of an organic accelerator are probably due to the joint addition of the two elements to the rubber molecule.

ARMAMENT

33 *Toluene*

(S. J. Dickey, Army Ordnance, Vol. 7, No. 40.) (9.8/5277 U.S.A.)

The article constitutes a general survey of toluene production, including a consideration of sources, recovery from coke oven and city gas, improvements in absorption recovery systems, special cracking processes, selection of oil for cracking and separation of paraffin and aromatic hydrocarbon oils.

34 *Flexure of Thick Circular Plates*

(C. A. Clemmow, Procs. Roy. Soc., 112, pp. 559-598, 1.10.26—abstr. in Sc. Abstr. A., 25.2.27.) (9.6/5329 Great Britain.)

This investigation arose out of a suggestion that the deflection of a circular steel plate, firmly held at the edge, might be used as a measure of high explosive pressures. The plate would form the base of a cylindrical closed vessel of the usual type, and the measurement made would be that of the normal central deflection of its external flat surface. Three types of solution of the problem have been considered; (1) that in finite terms; (2) that in infinite series involving hyperbolic functions of z and Bessel functions of r; (3) that afforded by a combination of (1) and (2); r and z are cylindrical co-ordinates and $2h$. is the thickness. No one of the above has been found to solve the problem in its complete generality; (1) leads to the usual results for thin plates of neglected thickness; (2) is of restricted application, as boundary conditions at the edge referring to one displacement only can be satisfied; (3) in various forms permits of the discussion of a variety of problems, the method being to satisfy the stress boundary conditions over $z = \pm h$, and then to consider different boundary conditions at $r = a$. Methods have also been indicated for the discussion of the problem for the case of non-uniform loading, particularly when the load is concentrated entirely at the centre. The theoretical results for thick plates are expressed in the form of infinite series, which have been reduced to simple terms so that concise approximate expression for stresses and displacements are obtained which are valid in most cases, even for comparatively thick plates. The paper is mathematical throughout, and the distribution of stress throughout the plate in the cases considered is given by tables.

35 *Husan-Andrews Enemy Speed Finder*

(Engineering, 18.2.27.) (9.56/5287 Great Britain.)

An instrument made by Messrs. Henry Hughes for determining the speed and course of an enemy ship attacked by torpedo-carrying aircraft is described and illustrated.

AIRSHIPS

36 *Helium*

U.S.A. helium supply. (A. and N. Register, 18.12.26.) (12.62/5185 U.S.A.)

It is stated that the shortage of helium is seriously handicapping both Army and Navy airship operation in the U.S.A. and is preventing the development and storage of reserve of helium. The Army is stated to have about three million c. ft., and the Navy about 2½ million c. ft., and in each case it is nearly all in use; the cost of production is given as being fifty dollars per thousand c. ft.

Helium. (U.S. Air Services, March, 1927.) (12.62/5334 U.S.A.)

Rather more than a million dollars (£200,000) has been voted for helium for the next fiscal year. The whole amount is intended for an extension of the sources of supply for the helium-bearing natural gas. It is stated that an adequate supply of helium will thereby be assured for Army and Navy airships for a number of years. The amount given above does not include further amounts for the purchase of helium during 1928.

37 *Pressure Distribution on Hulls*

Estimation on Pressure Distribution on Airship Hulls. (Th. v. Karman, Researches at the Aachen Technical High School.) (12.31/5531 Germany.)

Model calculations are given for the Z.R.III. hull form with the following simplifications :—All external organs are supposed to be removed, and each section is replaced by a circular section of equal area. The calculations are then carried out for axial motion and for oblique motion. In both cases a velocity potential is assumed. In the first case the resultant drag due to normal pressure forces is zero. In the second case a resultant couple is produced which tends to turn the airship broadside to the relative wind, but there is still no resultant force. To estimate the latter case in which the pressure distribution especially at the bows is seriously modified, it is assumed that a vortex formation follows the hull, much as in the case of an aeroplane wing. Suitable assumptions as to the distribution of vorticity actually lead to good agreement with the experimental determination. The author states that he has made calculations with reference to other forms investigated experimentally (by Fuhrmann and on English models) and has found very satisfactory agreement. A warning is added that in general critical points may exist requiring special treatment. He considers that a continuous distribution instead of a step by step distribution of sources will satisfy every case, and justify the method to mathematicians.

38 *Substitutes for Gold-beaters' Skin*

(Aviation, 14.2.27, p. 323.) (12.63/5281 U.S.A.)

In the course of an article on the present airship situation in the United States, Commander Rosendahl states the experimental work has been carried out on a substance known as Cellophane, which would replace the gold-beaters' skin now used in the construction of the gasbags of airships.

MISCELLANEOUS

39 *Meteorology*

Equations of atmospheric disturbances from a steady state. (v. Bjerknes, Oslo, Z.f.A.M.u.M., Feb., 1927, pp. 17-26.) (6.23/5311 Germany.)

The author premises the intractable nature of the general equations of viscous fluid motion and proposes as a first step the investigation of small disturbances of an initially steady state.

The general equations are written down and reduced to known solutions in the very simplest cases. For more general solutions various simplifications are

suggested. Various general conclusions are drawn from the form of the differential equations. An appreciative reference is made to Appell's Traite de Mecanique Rationelle, Vol. III. Appeal is made to mathematicians to develop methods of solution, and to meteorologists to look at the problem as a hydrodynamical one and to advance by empirical methods.

Application of the equations of hydrodynamics to meteorology. (H. Hergesell, Works of the Prussian Aeronautical Observatory, Lindenberg, Vol. 15, 1926, pp. 155-162.) (6.23/5538 Germany.)

The author discusses the significance of the usual meteorological data as space-means and time-means, and examines the validity of inserting daily and yearly means in the equations of hydrodynamics which hold strictly only for instantaneous values. In reducing n systems for n points of observation by use of the arithmetic mean, additional terms arise from the correlation between the meteorological data, but are negligibly small as appears from use of thirty years' records at Stykkisholm.

40 The Use of Models in the Solution of Indeterminate Structures

(G. E. Beggs, Franklin Inst., Vol. 203, No. 3, March, 1927.) (12.2/5570 U.S.A.)

In order to avoid laborious mathematical solutions a practical method of solving many types of indeterminate structures by the aid of elastic models has been developed. It is based upon the fundamental principles underlying many mathematical methods, in particular Maxwell's theorem of reciprocal deflections. Each indeterminate quantity is directly expressed as a function of a known load and two measurable deflections. Furthermore, since the solution by use of models allows all stress components to be determined from measured deflections, there remains for checking purposes the three unused equations of statical equilibrium. The article discusses the underlying principle of the solution of structures by the use of models and illustrates the apparatus used.

41 The Measurement of Transmission and Reflection of Sound by Partitions of Various Materials—I. Felt-Like Materials

(A. H. Davis and T. S. Littler, Phil. Mag. S. 7, Vol. 3, No. 13, Jan., 1927.) (5.61/5186 Great Britain.)

The paper is part of a study of the transmission and reflection of sound by various partitions, and relates mainly to partitions of a felt-like nature. The method used is on the general lines of that due to F. R. Watson. The partition is clamped over an aperture in the wall between two adjacent sound-proof rooms, in one of which a source of sound, in conjunction with a paraboloidal mirror, directs a fairly uniform beam of sound obliquely on to the partition. Measurements of intensity are made in the transmitted and reflected beams and at various other points within the rooms. A description is given of the electrical equipment used in the production and measurement of the sound-field. A detailed study of the field of sound in the two rooms was made both with and without a partition over the aperture. The results of this exploration showed that transmission and reflection ratios were almost independent of the positions in the beam at which the measurements were made. A number of partitions were tested, and the consistency of the results is indicated in graphical form. The transmission of sound through felt was specially investigated. Four partitions of hair-felt, each of 0.58in. thickness, were employed, and the transmission through one, two, three and four layers was studied. A number of frequencies ranging from 250 to 1,600 vibrations per second were used, and curves are given showing the results obtained. A comparison is made between these results and those obtained by P. E. Sabine, who used a reverberation method.

42 *Retention of a Ball by a Vertical Water Jet*

(W. C. Baker, Science, 64, pp. 161-163, 13.8.1926. Abstracted in Sci. Abstr. A., Vol. 30, No. 349.) (6.32/5180 U.S.A.)

A ball, mounted on a horizontal axis, the horizontal pull on which is measured by a delicate spring device, and provided with vertical slide on which the water can impinge on leaving the ball, shows the following facts. When the ball is at such a height that its weight is balanced by the vertical thrust of the jet and the slides are drawn to allow free passage for the water leaving the ball, the ball is acted on by a horizontal force varying with the point of impact, increasing to a maximum of about half the weight of the ball if the latter is allowed to rotate freely about its horizontal axis. The force is lessened by about 40 per cent. if the ball is fixed. If the slides are closed, the impact of water on them entirely neutralises this horizontal pull. It is concluded that the force is entirely due to the creation of a horizontal momentum component, and that the law of Bernoulli plays a very small part in causing it.

43 *Selenium Cells*

(J. of Sci. Instruments, Vol. 4, No. 2.) (6.79/5179 Austria.)

An account is given of a demonstration of selenium cells made by Professor Thirring, of Vienna, before the Physical Society. He considered that the best method of getting over the inertia of the selenium is to cut the light up into flashes by a revolving sector disc, amplify the fluctuations and rectify them by a shutter on the spindle of the disc. By this means and by focussing the light of a distant small lamp on a cell in a camera, he stated that it had been found possible to effect reliable communication over a channel three miles wide in broad daylight.

DYNAMICAL FORCES IN AIRCRAFT ENGINES

SOME OBSERVATIONS ON MAJOR CARTER'S PAPER

BY CAPTAIN J. MORRIS, B.A., A.F.R.AE.S.

1 On the Question: Should the Running Speed be above or below the Critical Speed, and if so, by how much?

Major Carter has dealt with this question in his paper. He has originated a method and invented an expression. With his "resonance factor" as weapon he has started a crusade against the enemy and sees prospects of converting him into a friend.

As Major Carter has stated that he got the idea on reading my article on "Whirling Shafts" in the *Automobile Engineer* for March, 1925, I propose to examine the basis of his inspiration and test his conclusions.

Consider the case of a load W lbs. rigidly attached to a light shaft, free to run in any bearings (see Fig. 1).

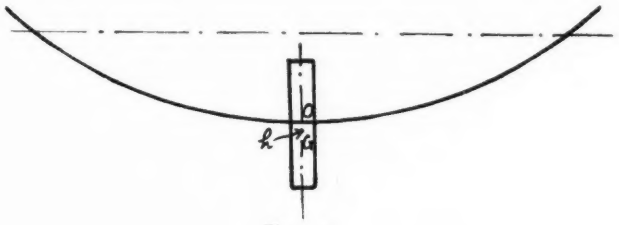

FIG. 1.

Let O be the point where the axis of the shaft cuts the transverse plane of the load when at rest. Let G be the centre of gravity of the load (not necessarily coincident with O) and let $OG=h$ ins., this representing amount by which the load is out of balance. The load is regarded as concentrated, that is, of negligible moment of inertia about a lateral axis. If now the shaft is rotated with constant angular velocity w, the path of the displaced point O will be a circle of radius.

$$r=\pm hw^2/(w_c^2-w^2)$$

according as w_c^2 is greater or less than w^2, where w_c is the critical angular velocity answering to whirling.

If now the load is regarded as massless, but the forced vibration due to its being out of balance still acts, then O will describe a circle of radius

$$\rho=hw^2/w_c^2$$

Major Carter takes the ratio

$$r/\rho$$

and calls this a "Resonance Factor" (R.F.) and so obtains

$$\text{R.F.}=r/\rho=\pm 1/(1-x^2)$$

where $x=w/w_c$

$w/2\pi$ being the frequency of rotation of the shaft and $w_c/2\pi$ the natural frequency of the system in lateral vibration without imposed rotation.

Let us now plot the expressions r, ρ and R.F. on an w^2 base (see Fig. 2).

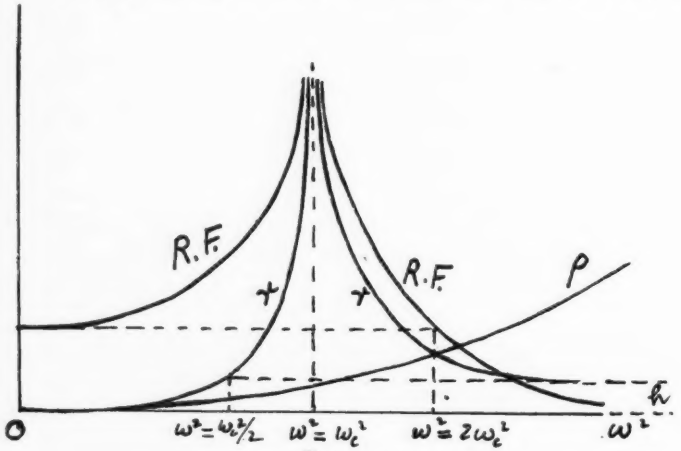

FIG. 2.

To take r first, when $w^2=0$, $r=0$. As w^2 increases to the value $w^2=w_c^2$, r steadily increases to infinity. Thence with increase in w^2, r steadily diminishes until finally for an infinite value of w^2 it drops to the terminal value h.

Clearly the best range for r will be given by

$$w^2=0 \rightarrow w_c^2/2$$

which means that the shaft will be least deflected in this range and so will be least stressed. Hence the running speed should not exceed the value

$$w=w_c/\sqrt{2}$$

where w_c is the critical speed answering to whirling.

On the resonance factor basis the actual best range is given by

$$\text{R.F.}=1 \rightarrow 2$$

Further, the shaft is less stressed for a resonance factor just under 2 than for a resonance factor 0.

According to Major Carter's argument the resonance factor is less than unity beyond the value

$$x^2=2 \quad \text{or} \quad w^2=2w_c^2$$

and hence for speeds in excess of $\sqrt{2}w_c$ the shaft should run best (for what reasons I cannot fathom). Major Carter has in fact reasoned by relation and not from the actual; he has in consequence performed a fallacious somersault as a cursory inspection of Fig. 2 will show. From this it will be seen that a high resonance factor may be associated with a low actual displacement and vice versa.

Exactly the same thing applies to his resonance factor argument in the torsional case. In fact with the parabolic law between engine torque and speed, as assumed by Major Carter in his Fig. 8, the analogy is exact. So much for the basis of the resonance factor argument and its true significance.

There is, however, a good deal more in the problem than is manifested by Major Carter's resonance factor.

The problem as I view it is to provide data to enable a designer to determine the most suitable dimensions for a shaft able to withstand the stresses involved in running, great regard being had to lightness. I say suitable advisedly. For example, if the ideal shaft is an infinitely long wire of infinitely small radius it

will not do for an aircraft engine; likewise if the ideal shaft is infinitely thin disc of infinite radius.

To make matters clear consider the case of a single-throw radial engine.

Let I be the polar moment of inertia of the crank system and let c be the torsional stiffness of the crankshaft between airscrew and crank.

In running at N r.p.m. the gas torque up to the first harmonic will be of the form

$$A_N + B_N \cos wt$$

where

$$w/2\pi = nN/120$$

n being the number of cylinders of the engine.

The equation of motion for torsional oscillation will be

$$p\ddot{\theta} + c\theta = A_N + B_N \cos wt \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where θ is the angular displacement between crank and airscrew (supposed of large inertia) and $p = I/g$.

The particular solution of (1) is

$$\theta = A_N/c + B_N \cos wt/(c - pw^2) \quad . \quad . \quad . \quad . \quad (2)$$

so that θ will vary between

$$A_N/c \pm B_N/(c - pw^2)$$

A_N and B_N are for the present regarded as constant. Thus the shaft will be subject to

(1) A mean torque A_N . . . . . (3)

(2) A torque variation $B_N c/(c - pw^2)$ . . . . (4)

We will first consider the problem of determining the most suitable dimensions for least stress subject to A_N, B_N, p and w being constant. On the assumption that the shaft is solid, the stresses due to (3) and (4) will be

(1) A mean stress $2A_N/\pi r^3$ . . . . . (5)

(2) A stress variation $2B_N Cr/(C\pi r^4 - 2lpw^2)$ . . . (6)

where C = modulus of rigidity.

r = outer radius of shaft.

l = length of shaft.

To proceed further we require some basis for the investigation of the strength of a shaft subject to both a mean stress and a stress variation. We might take the maximum stress as a basis, but may not be entirely satisfactory. Here we have expert guidance from Professor Lea, who has done a considerable amount of research on the effects of repeated stresses. He has suggested the following formula* as applicable to the above problem:—

$$S_r = S_o(1 - f_m/f_1) \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where S_o = Outside range of Stress for zero Mean Stress.

f_m = Mean Stress.

S_r = Outside range of Stress Variation for a Mean Stress f_m.

f_o = Working range of Stress Variation.

f_1 = Ultimate Stress.

Thus

$$\text{Factor of safety} = F = S_r/f_o = S_o(1 - f_m/f_1)/f_o \quad . \quad . \quad . \quad (8)$$

We will apply this formula to the problem under discussion. We find

$$F = S_o(C\pi r^4 - 2lpw^2)(1 - 2A_N/\pi r^3 f_1)/2B_N Cr \quad . \quad . \quad . \quad (9)$$

in which sign is ignored.

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* "The Behaviour of Metals under Repeated Stresses," lecture delivered by Prof. Lea before the Lloyd's Register Staff Association, March, 1927.

We have arranged for only two variables, viz., l and r. We can now fix l and see how F varies with r; or we might fix r and vary l. We can if we choose fix the weight of the shaft, *i.e.*, we can make lr^2 constant. It is probable that in practice l will be confined within strict limits. We will therefore consider this case first.

In any case r will have a lower limit determined by the condition

$$f_m \text{ less than } f_1$$
$$i.e., \ \pi r^3 f_1 \text{ greater than } 2A_N$$
$$\text{or } r \text{ greater than } (2A_N/\pi f_1)^{1/3} \quad . \quad . \quad . \quad . \quad (10)$$

For this value of r, F will be zero. As r increases F will increase up to a maximum and will then decline to zero again for the value of r given by

$$C\pi r^4 - 2lpw^2 = 0 \quad . \quad . \quad . \quad . \quad . \quad (11)$$

For values of r above this F steadily increases and ultimately becomes infinite.

We might call r_c the critical radius corresponding to w, *i.e.*, the value of that radius for which w will be a critical speed for the shaft. Then

$$C\pi r_c^4 = 2lpw^2$$
$$\text{or } r_c = (2lpw^2/C\pi)^{1/4} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

F will thus attain a maximum value somewhere in the range

$$r = (2A_N/\pi f_1)^{1/3} \rightarrow (2lpw^2/C\pi)^{1/4} \quad . \quad . \quad . \quad (13)$$

If in this range a value of r can be found which gives a sufficient factor of safety, then we have found the smallest value of r for our purpose provided the critical speed for such r is outside the normal running range. In such circumstances

$$r \text{ will be less than } r_c$$

so that the shaft will be such that its critical speed is below the actual speed. In fact if w_c be the critical speed corresponding to the r chosen then

$$C\pi r^4 = 2lpw_c^2$$
$$\text{and } C\pi r_c^4 = 2lpw^2$$
$$\text{whence } r^4 w^2 = r_c^4 w_c^2$$
$$\text{or } w_c = r^2 w / r_c^2 \quad . \quad . \quad . \quad . \quad . \quad (14)$$

If on the other hand there is no value of r below r_c for which there is the requisite factor of safety, then the least value of r for which this condition is satisfied will be greater than r_c and in consequence

$$w_c \text{ is greater than } w$$

We might examine Major Carter's data in his Fig. 8 (reproduced below) in the light of Professor Lea's formula.

Major Carter does not inform us as to the means by which the stiffness of the shaft which has a synchronous speed at 820 r.p.m. (Case 1) was reduced nor by what means that for which the synchronous speed is 2,460 r.p.m. (Case 2) was increased. If these stiffnesses were obtained by variations in the radius of the shaft which had a synchronous speed at 1,640 r.p.m. we find—

Case 1—

Mean torque = 1,300 lbs. ins.
Torque variation at 1,640 r.p.m. = 200 lbs. ins.

Case 2—

Mean torque = 1,300 lbs. ins.
Torque variation at 1,640 r.p.m. = 1,000 lbs. ins.

Now if r_1 and r_2 be the respective radii

$$C\pi r_1^4 = 2lp\,(820)^2$$
$$\text{and } C\pi r_2^4 = 2lp\,(2460)^2$$
$$\therefore \ r_2^4 = 9r_1^4$$
$$\text{or } r_2 = \sqrt{3}\, r_1$$

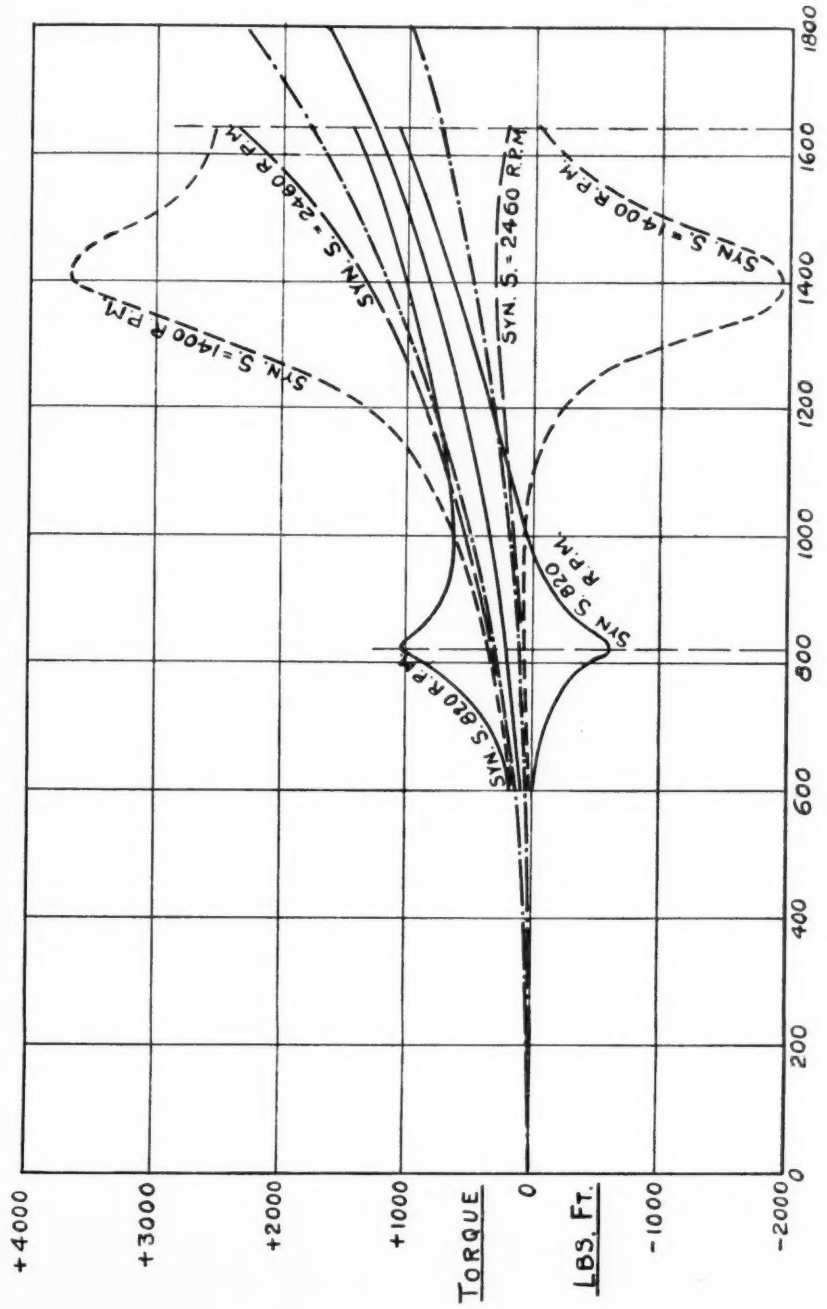
+4000
+3000
+2000
+1000
0
-1000
-2000
TORQUE
LBS. FT.
0
200
400
600
800
1000
1200
1400
1600
1800
SPEED IN R.P.M.
SYN. S. = 1400 R.P.M.
SYN. S. = 2460 R.P.M.
SYN. S. = 1400 R.P.M.
SYN. S. = 2460 R.P.M.
SYN. S. 820 R.P.M.
SYN. S. 820 R.P.M.

Fig. 8.

Thus

$$F_1 = S_0 \pi r_1^3 (1 - 2000/\pi r_1^3 f_1)/400$$
$$F_2 = S_0 \pi r_2^3 (1 - 2000/\pi r_2^3 f_1)/2000$$
$$F_2/F_1 = 400\, r_2^3 \lambda / 2000\, r_1^3$$
$$\text{or } F_2/F_1 = 1.4\, \lambda$$
$$\text{where } \lambda = (1 - 2000/\pi r_2^3 f_1)/(1 - 2000/\pi r_1^3 f_1)$$
$$\text{and since } r_2 \text{ is greater than } 1$$
$$\lambda \text{ will be greater than } 1$$

Hence F_2 is nearly 50 per cent. greater than F_1.

Thus in spite of the greater stress variation in Case 2, the actual stress in the shaft at 1640 r.p.m. is less than that for Case 1 at the same speed. And yet the resonance factors are respectively 9/5 for Case 2 and 4/5 for Case 1. If on the other hand he kept his radius constant and varied the stiffness by respectively increasing and decreasing his length, he would be using a shaft for Case 1 nine times the length of that for Case 2. He might thus get a better factor of safety for Case 1, but the apparently better shaft would be impossibly long and altogether outside the range of practice.

Reverting now to Professor Lea's formula for F we will keep r constant and vary l.

In this case F will have the value

$$(S_0 \pi r^3 / B_N)(1 - 2\, A_N / \pi r^3 f_1)$$

for the value $l = 0$; will drop to zero for the value $l = l_c$ where

$$C\pi r^4 = 2\, l_c p w^2$$

and will then increase indefinitely with l.

For the value $l = 2\, l_c$, F (ignoring sign) will have the same value as for $l = 0$. In this case if no value of l in the range

$$l = 0 \rightarrow l_c$$

gives a sufficient factor of safety we will have to choose a value of l above $2\, l_c$.

If w_c is the critical speed corresponding to any particular value of l, then

$$C\pi r^4 = 2\, l p w_c^2$$
$$\text{Also } C\pi r^4 = 2\, l_c p w^2$$
$$\text{Hence } l w_c^2 = l_c w^2$$
$$\text{or } w_c = w\, (l_c/l)^{\frac{1}{2}}$$

Thus if a sufficient factor of safety can be found for a value of l in the range 0, l_c the critical speed of the shaft will be above the actual running speed. If on the other hand no value of l in this range is suitable then a value of l must be chosen in excess of $2\, l_c$, in which case

$$w_c \text{ will be less than } w/\sqrt{2}$$

i.e., the critical speed will be below $1/\sqrt{2} \times$ the actual running speed.

We will next take a particular shaft of constant dimensions and study its behaviour at different speeds. For this purpose A_N and B_N will have to be regarded as functions of N (and therefore w). Major Carter in his Fig. 8 assumes a parabolic law, viz. :—

$$A_N = \alpha w^2$$
$$B_N = \beta w^2$$

With this law equation (2) becomes

$$\theta = \alpha w^2 / c + (\beta w^2 \cos wt)/(c - pw^2) \quad . \quad . \quad . \quad (15)$$

so that θ will be between

$$\alpha w^2 / c \pm (\beta w^2)/(c - pw^2)$$

The angular variation will be

$$\theta_v = \pm (\beta w^2)/(c - pw^2)$$

θ_v is zero when $w^2 = 0$; it steadily increases up to infinity for the value w_c where

$$c = p w_c^2$$

Then for values of w^2 above w_c^2 θ_v steadily diminishes, attaining ultimately the terminal value β/p for an infinite value of w^2.

If in θ_v we put $w^2 = w_c^2/2$ we find

$$\theta_v = \beta/p$$

Hence the range for least angular variation will be

$$w^2 = 0 \rightarrow w_c^2/2 \quad . \quad . \quad . \quad . \quad . \quad (16)$$

i.e., when the shaft is running below its critical speed. Since also the mean angular displacement increases steadily with w^2 it follows that the range (16) will be that for least stress.

To sum up, the resonance factor argument, as used by Major Carter and reiterated by him on page 322 of his paper in reply to my criticism, is fallacious, because it makes small torque variation in the shaft at full throttle the criterion of perfection without regard to the actual strength of the shaft in relation to this torque variation.

2 *On the Question of Acknowledgment*

On page 28 of the proof of Major Carter's lecture he says:—"A chart based upon Captain Morris's equations is given in Fig. 14. This is reproduced from an article by Captain A. Swan and the Author in *The Automobile Engineer*, March, 1926, by kind permission of the Editor."

In the report of the lecture in the Journal this paragraph has been modified as follows:—"Fig. 14 is a chart reproduced from an article by Captain A. Swan and the Author in *The Automobile Engineer*, March, 1926, by kind permission of the Editor."

Well, well, Fig. 14 is wholly and solely a graphical representation of my formula for multi-throw engines published in the Journal for October, 1923.

Reply to Captain Morris's Observations

The first part of Captain Morris's further contribution does not touch the arguments put forward in my paper.

Arguing by the analogy of the whirling shaft, he concludes that the application of the "Resonance Factor" to the torsional vibration problems dealt with in the paper is fallacious, and then confronts *me* with having "reasoned by relation and not by the actual"!

Quite definitely, no mathematics in my paper is based upon the whirling shaft problem; each formula has been derived from equations of motion for torsional vibration.

When looking through the article on whirling shafts to which Captain Morris refers, certain similarities between his equations and those I had been using in torsional vibration investigations led me to realise some things I ought to have thought of sooner in view of marine developments. Marine engineers have had the matter clear for a long time. Thus "quill shaft drives" were introduced for geared turbines to put the initial speeds well below the running range, and the same device has been used with complete success in motor ships. Readers will find reference to this in the literature of the subject. The resonance factor is merely the outcome of working in terms of non-dimensional quantities—a device much used in aerodynamical investigations. Thus the equation

$$\text{Resonance Factor} = |\theta|/E = 1/\{(1-x^2)^2 + \Delta^2 x^2\}^{\frac{1}{2}}$$

is only a particular way of writing an equation which must have been obtained for the first time many many years ago.*

* See Hopkinson's excellent pamphlet, *Vibrations of Systems Having One Degree of Freedom*, Cambridge University Tracts.

The "Resonance Factor" is given in my paper as a convenient function to use in any particular investigation where the forcing harmonics are known for each chosen speed and running condition; it is not given as an "absolute interior," although, quite rightly, the importance of its values at full throttle speeds is emphasised. It is exactly defined and there is no real excuse for misunderstanding its significance, nor justification for suggesting that I am not perfectly clear in my mind about its application. One can only suppose that it is through approaching the matter from the whirling shaft analogy that Captain Morris has got befogged. Bringing the mathematics of whirling shafts into the discussion tends to confuse the issue for, in the cases taken in the paper, the forcing effects were external to the vibrating system whereas, in the case of the whirling shaft, the forcing effect is brought about by inertia and is proportional to the square of the rotation speed; nevertheless, in the case of the whirling shaft, the displacement is still the product of Forcing Effect and Resonance Factor.

Of course a low Resonance Factor may be associated with a high displacement if the forcing effect be large, and a high Resonance Factor may be associated with a low displacement if the forcing effect be small. Surely it is made abundantly clear in the paper (particularly in reference to Fig. 8) that it is not the Resonance Factor alone that needs to be considered in general.

The parabolic torque law was taken for the specific case of a particular engine running on the hangar with a particular airscrew fitted, and it does not follow that from the design standpoint one may take torque and torque variation to be proportional to the square of the speed and then argue by analogy with the whirling shaft case—for the designer does not fix the critical speed and then decide upon the running speed, but he settles the full torque running speed range as close as possible and places the critical speed or speeds as favourably as possible in relation to this speed range. In the case of the single-throw radial engine, if he can contrive to get the synchronous speed very low he can go through this at low throttle under all conditions of running and have a torque in the airscrew drive at full throttle for which the fundamental variation is the fundamental of the full throttle gas torque variation multiplied by a Resonance Factor which may be less than unity. Captain Morris tries to reduce the problems to a question of shaft strength alone, overlooking the fact that a smooth drive at the airscrew attachment may be worth having at the expense of adding a few cubic inches of steel to give the extra resilience required.

The more one thinks of the multitudinous questions involved, the more academic appears Captain Morris's attempt to solve the general case of optimum critical speed position in terms of shaft dimensions and stress, taking as basis what Gough refers to as the "Modified Goodman Formula."

There are important practical considerations arising in each particular case which cannot be taken into account mathematically; furthermore, shafts have bending forces to withstand as well as torques, and these are ignored by Captain Morris. The only course appears to be to consider each particular design problem as it arises, working out alternative schemes and deciding upon what appears to be the best compromise; whether a low main critical speed is feasible depends upon conditions.

I do not propose to examine Captain Morris's second portion in detail because I do not think it leads anywhere. He sums up this portion by proclaiming that I have been guilty of fallacious reasoning through attaching undue importance to small torque variation at full throttle, disregarding the consideration of stress. Those who have had to overcome airscrew and hub drive troubles know that a large torque variation is bad in itself, and they will note that Captain Morris has been led out of his depth by his mathematics. Again, it is very naive of Captain Morris to imagine that anyone concerned with crankshaft design really overlooks stress; he would almost as soon forget that shafts cannot be

made infinitely long and of infinitely small diameter, or that engines cannot be run at infinite speed. At present I can only assure Captain Morris that the stress question has never been overlooked, and leave it at that.

Is not Captain Morris's attitude on the question of acknowledgments rather absurd? In correcting the proof for the Journal I cut out his name in reference to Fig. 14 at the bottom of page 303, because it appeared in the previous line, and because I had made it quite evident in the additional matter on page 306 that the curves were plotted from his trignometric equations, as it is also from the "$\sin a/E$" on the graph itself. Thus, after his name on p. 306, there follows his notation and "the quantity $\sin a/E$ plotted in Fig. 14." The terms "could" and "would" are used in relation to the algebraic equations, indicating that they had not actually been used in the manner suggested. But, one may ask, how can the curves be "simply and solely" his when they could have been plotted from equations in use before he evolved his equations?

B. C. CARTER.

S. Farnborough, May 4th, 1927.

Note on Major Carter's Reply

I have read the above remarks by Major Carter and consider that in so far as any technical questions are involved, any reader can judge for himself as to the relative arguments advanced by Major Carter and myself. I would point out, however, that as a general proposition one cannot have it both ways. One cannot base conclusions on data derived from certain assumptions and then repudiate the validity of the assumptions made in order to support one's fallacious conclusions.

Major Carter's explanation of his cutting out my name in reference to his Fig. 14 is not very satisfactory. His argument that the graphs in this figure could have been obtained from equations in use before I evolved my equations makes matters worse. The fact remains that the graphs in question were definitely drawn from my equations and are in fact a graphical representation of my solution.

J. MORRIS.

REVIEWS

The Study of War

For Statesmen and Citizens. Major-General Sir George Aston, K.C.B. Longmans, 10/6 net.

Considering the very important part which war has played in the history of mankind, it seems remarkable that the study of war should have been so universally neglected. The institution of a School of War Studies in the University of London is therefore an event of supreme importance. It forges a missing link in the chain of research into those factors which shape the course of the human race.

For the session 1925-1926 the Military Education Committee of the University of London arranged for a series of lectures to be delivered on the various aspects of warfare by leaders of thought in the three fighting forces. These lectures supplemented by other dissertations of distinction have been edited by Sir George Aston, and the result is an eminently useful book on the Study of War.

The book opens with an introductory address by Viscount Grey of Fallodon. Lord Grey points out that as we are governed not by soldiers or sailors but by civilians who are likely to play a part in the Government in time of war, it is important that such civilians should study the principles of war and particularly the great mistakes which civilian Governments have made in military and naval strategy in the past. He also urges that it is especially essential that the study of war in all educational institutions should be brought up to the point of bringing home to each generation what modern war really means. "The study of war," he says, "would show that any future war will be even more destructive to human life and property than the great experience we have all been through."

The inaugurating lecture entitled "The Study of War" was delivered by Sir George Aston himself. In this the distinguished General puts forward two points as worthy of attention, viz.*:—

> (1) That ignorance is one of the causes of war, only to be cured by knowledge of its nature; and
>
> (2) That it is the duty of those who conduct operations of war to prepare themselves by study to bear that heavy responsibility.

Taking a cue from Clausewitz he considers that war belongs not to the province of arts and sciences, but to the province of social life differing from other great conflicts of interests—such as business competition—only in the fact that it is settled by bloodshed. His main theme, however, is the review of various ideas on war with the purpose of urging the importance of its study.

Next follows "A Defence of Military History"* by Sir Charles Oman. Sir Charles holds that history is not a mere logical stream of events, but a series of happenings, affected in the most inscrutable fashion by incalculable things. He vigorously combats the vague theories of inevitable world movements. War he regards as resulting mainly from the appearance of individual human beings of unusual endowments—"cataclysmic" personalities as he calls them. He deprecates as unworthy the handing over by historians to the military specialist the study of the methods by which these "cataclysmic" personalities made war. Adopting the maxim "what touches all is the business of all," he asserts that it

* Paper read before the Conference of British and American Historians at the Institute of Historical Research in July, 1926.

is no more right to hand over the study of military history to professional soldiers alone than it would be to permit no one but lawyers to touch constitutional history. Ministers, he urges, should have some knowledge of their own and not be bound to accept blindfold the orders of the military mentor. "The better acquainted with the rules of war the Minister may be," says Sir Charles, "the less will he be tempted to interfere without necessity, and the less unreasonable his suggestions prove. . . . Generals are no more infallible than Ministers; and looking down the record of the ages we may conclude that each class has had only too much occasion to rail at the other, and that neither should claim omniscience, infallibility, or omnipotence."

Two lectures on "Sea Warfare" by Vice-Admiral Sir H. W. Richmond follow. They occupy a little more than a third of the whole book. As a concise exposition of the history and development of the principles of naval warfare they would be difficult to improve upon. Steering clear of all controversy, Admiral Richmond epitomises his vast store of knowledge of the subject of sea warfare and presents the reader with a reasoned array of indisputable facts. He considers that the influence of aircraft on war at sea is likely to be as far-reaching as the introduction of any other new form of fighting vessel has always been, but that air operations must be conducted on the principle of co-operation with the other arms.

But perhaps Admiral Richmond's most important opinion on air power is summed up in the following extracts:—"Short cuts to victory, attempts aimed at the final objective, have an almost unbroken record of failure. The doctrine of victory by evasion, direct attack upon the people's life without overcoming their armed forces, can find no support in the experience of war. It is a theory only, yet to be proved."

. . . . . .

"It is constantly being impressed upon us that a fatal blow at what is figuratively called the 'heart' may be delivered from the air; and that to guard against it one must increase those forces which alone can give protection—air forces—obtaining the methods to do so by reducing naval force. But let it not be forgotten that though the new danger has come into being, the danger to which we nearly succumbed during the war—investment by sea—will be as fatal ten or twenty years hence as it was ten years since—probably, indeed, more so."

Sir William appears to base this argument on the premise that a country will succumb on an empty stomach more surely than from shattered nerves. This may be matter for debate, but experience seems to show that the moral effect of continuous air-bombing may be as effective as the stranglehold of starvation in compelling compliance.

Land warfare is dealt with by Major-General Sir Edmund Ironside, who does not present too hopeful a picture for the future of the British military forces. With a small regular nucleus and equally small second line forces scattered over the whole globe, he sees that any enemy will have the advantage of the initiative. British "feverish improvisation and slowness of development" will be great handicaps. He does not agree with the school of thought that asserts that air forces alone will in future be able to destroy the power of resistance of a nation before its land forces can be brought into play. He considers that a European campaign will open with a fight for the mastery of the air, and during this phase the direction of affairs will be in the hands of the air authorities. There can be no question of the immediate despatch of an expeditionary force such as there was in 1914. On the supposition that any future European war in which we are likely to be engaged will be waged in co-operation with some ally, the expeditionary force will only be able to depart after a sufficient security against air attack has been achieved. He foresees that in the field the bases and communications of our army overseas will no longer be safe from attack. The forward fighting troops will be unable to protect them against attack from the air and by

mobile mechanical columns. The rearward services will have to be prepared to protect themselves against these new attacks by dispersal, camouflage, and anti-aircraft fire, or the fighting impetus of their own troops in front will be crippled from the outset for want of food and ammunition.

He does not think that there will ever be trench warfare again as in 1914-1918. Land forces of the future, he thinks, will be much smaller than they have been in the past, and will be very largely mechanical, with tanks, armoured cars, tractor guns, and infantry in motors, all capable of great speed and endurance. In short, he considers the next war will be won by the nation that knows how to conserve its man power by machines. Landings, he thinks, will be ticklish affairs if opposed. Dual control in the past led to great difficulties, but with triple control of navy, army and air forces there will be more need of careful co-ordination than ever.

Air Vice-Marshal H. R. M. Brooke-Popham, who deals with air warfare, naturally finds himself at a disadvantage compared with his naval and military co-lecturers. They had the experience of centuries to draw upon, while he was confined to the solitary experiment of the use of air forces in the last war. Consequently his opinions are based partly upon experience and partly upon deduction. His first point is that man's mechanical genius has outstripped his reasoning powers and he has produced machines the use of which he perceives but dimly. He maintains that it is of the highest importance to develop the air sense not only in the R.A.F. but also in the nation as a whole. He discusses in some detail how a modern air force can assist the sea and land forces. Air fighting, he says, is by its nature indecisive. "We can hardly ever hope to destroy an enemy's air force, we can never ensure a permanent command of the air; all that we can do is to obtain a local and temporary superiority. There will be much fighting in the air, there will usually be a continuous struggle for this local superiority, but there will be nothing corresponding to the Straits of Tsushima or to Sedan."

The main objective of an air force, he insists, is to bring pressure to bear upon the enemy people so that they will force their government to sue for peace. During the last war, enemy aeroplanes dropped a total weight of about thirty tons of bombs on London, and the casualties were 432 killed and 1,448 wounded. But, says Air Vice-Marshal Brooke-Popham, "it is quite possible that three or four times this weight of bombs may be dropped every twenty-four hours in another war unless our defences are adequate and efficient."

He emphasises the importance of the problem of how best to combine the three services, how to draw the most value from "the resisting power of an army, the mobility of a navy, and the striking power of an air force."

Next follows a lecture on chemical warfare by Brigadier-General H. Hartley. His first point is that as any future war must be national in character and gas is known to be an effective weapon, easily and cheaply manufactured in industrial plants and offering great opportunities of surprise, it is almost certain to be used despite any previous agreements to the contrary. He gives statistics to prove that the employment of gas is no more cruel than other weapons. He then traces the history of the gas operations of the last war. As to the future, he considers that gas used at the right place and moment and in adequate amount offers brilliant possibilities, but he adds "theoretical victories might well be won with other weapons on the same assumptions."

Visualising the different phases of a future war, he thinks the beginnings will be very different from the past. Instead of a period when the efforts of each combatant are concentrated on their own mobilisation, an aggressive power will do its utmost to strike a decisive blow at the outset by means of a mobile force and aircraft, and to paralyse the enemy's preparation. In these initial blows, whether they are struck at political centres or at mobilisation centres, gas is likely to be used both on account of its moral effect and of the disorganisation it might

produce before defence measures were properly organised. At this stage comparatively small quantities of persistent gas might have considerable effects at vital points, which might be attacked successfully from the air before anti-aircraft forces had been completely mobilised."

The last item in the book is by G. F. Bridge on "What should we teach about war?" His view is that when treating of war the teacher's duty is neither to condemn nor to glorify wholesale, but to lead boys and girls to ask about every war whether it was necessary—whether it had any legitimate or excusable feeling behind it, or whether it was merely a war of unscrupulous aggression, etc. Further, boys and girls might be shown how the conscience of the world about war has changed and is changing.

The foregoing only gives a cursory insight into this most valuable and stimulating volume. Sir George Aston has performed a great public service in producing this book; so have Messrs. Longmans in publishing it.

J. MORRIS.

Der Luftschiffbau Schütte-Lanz 1909-1925

Edited by J. Schütte. (R. Oldenbourg, Munich and Berlin.)

This book gives the history of the building of the famous German airships down to the winding-up of the concern, owing partly to the damping influence exerted by the Inter-Allied Commission, and partly to unhappy financial undertakings, in 1925. Curiously enough, there is little reference to the war, as such, nor to the exploits of the S-L's in the raids. The book, apart from technical details, is mainly propaganda, an attempt to allay the suspicion which is apparently felt in Germany towards the firm which independently started to build airships after Zeppelin's first successful experiments.

The differences of detail between a "Zeppelin" and a "Schütte-Lanz" are emphasised throughout the book. The main portion forms a valuable account of the construction of airships in Germany, different sections of the work being written by experts in their particular line. The latter part deals with the history of the undertaking. Pathetic is the picture of the erstwhile hive of industry at Zeesen, reduced to inaction, with "Versailles!" painted on the roofs.

Ergibnisse der Aerodynamischen Versuchs-anstalt zu Göttingen, III.

Edited by L. Prandtl and A. Betz. (R. Oldenbourg, Munich and Berlin.)

The third report from Göttingen deals (rather disappointingly) with statistical work. Perhaps this is to be expected, since the aerodynamical work at this famous laboratory has now reached the stage where its exponents can pause to look round and consolidate their past work.

The theoretical section deals with resistance and vortex-formation without containing anything outstandingly new. The practical work includes details and polar curves of a large number of aerofoil sections; this forms the major portion of the book. Interesting are those referring to aerofoils with "bites" taken out of the leading edge; those with end-discs to show the improvement obtained by reducing the end-losses of finite aerofoils; and aerofoils with slits. The work at Göttingen includes some but remotely connected with aeronautics; measurements of the aerodynamic forces on model gasometers, girders and railway carriages are included in the report.

DANIEL GUGGENHEIM SAFE-AIRCRAFT COMPETITION

FOREWORD

(The importance of safety in the air cannot be exaggerated. The Daniel Guggenheim Fund for the Promotion of Aeronautics have recently inaugurated a competition for the encouragement of Safety Devices, and issued rules in connection with the Competition. The Council feel that the Competition is of such importance that the widest publicity should be given to the rules governing it. They have decided, therefore, to print these rules in full in the following pages.

The Daniel Guggenheim Fund for the Promotion of Aeronautics is a fund which was formed to promote aeronautical education throughout the world. Owing to the wide publicity given to its objects, the exceedingly generous way the terms of its Trust Fund are being carried out, and the experience and authority of those who are administering it, it is bringing about a state of air-mindedness throughout the world far more rapidly than has been achieved by other methods. It will be remembered that in 1926 the Trustees of the Fund made the generous contribution of £1,000 to the Royal Aeronautical Society, enabling it to extend its activities in many directions and carry out the common object of the Daniel Guggenheim Fund for the Promotion of Aeronautics and the Royal Aeronautical Society, "the promotion of the Science of Aeronautics."
—EDITOR.)

THE DANIEL GUGGENHEIM SAFE-AIRCRAFT COMPETITION

The Daniel Guggenheim Fund for the Promotion of Aeronautics has recognised from the outset that any effort to make air traffic an integral part of our national commercial life must first reduce and as nearly as possible entirely overcome the popular scepticism of air transportation. In meeting this problem the Fund has dealt frankly with aeronautical development as it stands to-day, and, far from glossing over the fact that air travel is still attended by some risks, it has regarded those risks as one of the fundamental reasons for its own existence. The very first of its four general purposes is "to promote aeronautical education, both academic and general," and thereby to acquaint the public at large with the remarkable advances man has achieved in conquering the air and the astonishing degree of safety he has already attained.

As a fundamental step in its educational programme the Fund has planned and is hereby announcing a Safe-Aircraft Competition, by which it hopes not only to demonstrate that airplane travel is basically as safe as railway and steamship travel, but to stimulate scientific investigation and practical invention into evolving new devices and principles whereby air travel will convert even the most confirmed sceptics and will take its place in our lives as the fleetest, cleanest and safest of the three recognised modes of travel to-day.

The Daniel Guggenheim Safe-Aircraft Competition has been prompted by a conviction of the necessity and feasibility of aerodynamic safety. Its object is "to achieve a real advance in the safety of flying through improvement in the aerodynamic characteristics of heavier-than-air craft, without sacrificing the good practical qualities of the present-day aircraft."

To this end the Fund is offering a First Prize of $100,000 and five "Safety Prizes" of $10,000 each, which will be awarded in accordance with the Competition Rules set forth in the following pages.

The whole development of aeronautics in the past decade has been greatly influenced by the exigencies of war. Safety is a civilian rather than a war-time need, and for commercial purposes must be made of importance surpassing that of war requirements which are sometimes bought at the price of danger.

Flying operations are daily making great progress in the training of personnel, in the establishment of airways and airports, the perfection of ground organisation, and lastly in improvement of communication and meteorological services in which there still remains so much to be accomplished. There has likewise been great progress in improvement of equipment, particularly in power plant reliability, structural safety, removal of fire hazards, and development of auxiliary flying equipment.

Important progress has also been evidenced in many excellent designs by both American and foreign manufacturers in the aerodynamic qualities of aircraft, but this progress has been primarily directed towards efficiency rather than safety. In some of the basic features of aerodynamic safety, the design of most aircraft in use to-day, with notable exceptions, has not progressed much since the memorable flight of the Wright brothers at Kitty Hawk.

The rules of the Competition have been drawn to encourage development along the lines of safety, and have been drafted with the collaboration of aeronautical experts in many parts of the world. A preliminary and tentative draft of the rules was made in the first instance with the technical advice of Professor Alexander Klemin and Major R. H. Mayo, assisted by Mr. Archibald Black. In their final preparation, through the courtesy of Assistant Secretary of War Davison, the valuable assistance of Lieutenant E. E. Aldrin was made available. In addition, special consideration from the pilot's viewpoint has been given to the rules by Major R. W. Schroeder, Lieutenant James Doolittle, and Mr. J. B. Hill, veteran Air Mail Pilot.

Grateful acknowledgment is here made to these gentlemen for their earnest and splendid contributions in the cause of this Competition. Because of their number it is not possible to mention the names of the many organisations, manufacturers, engineers, pilots and scientists in America and Europe through whose invaluable advice and constructive criticism the completion of these rules has been made possible. Perhaps their efforts will bear fruit by inspiring progress through the very suggestiveness of rules.

Applications for entry in the Competition will be received on and after September 1st, 1927, these to be accompanied by a statement giving in so far as possible the information called for in Appendix I. The Competition will be held on some field near New York City, the exact location to be announced on September 1st, 1927. The Judges will be:—Mr. Orville Wright, Chairman; Mr. F. Trubee Davison, Assistant Secretary of War for Aeronautics; Mr. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics; Mr. William P. MacCracken, Jr., Assistant Secretary of Commerce for Aeronautics; Commander R. E. Byrd and Dr. George W. Lewis. The technical advisers will be three in number:—Professor Alexander Klemin, Lieutenant E. E. Aldrin and Major R. H. Mayo.

The Competition will be closed either on October 31st, 1929, or at any time prior to that date when the Fund may consider that the object of the Competition has been achieved. Tests will be carried on and judged from time to time throughout the period.

The Fund cherishes the hope that the Competition will bring forth new inventions and ideas which will not only mark a notable advance in the whole field of aeronautics, but will go far towards establishing air transportation as an obvious, superior and safe mode of travel of infinite benefit to the human race.

HARRY F. GUGGENHEIM.

April 30th, 1927.

RULES FOR THE DANIEL GUGGENHEIM SAFE-AIRCRAFT COMPETITION

Object of the Competition

The object of the Competition is to achieve a real advance in the safety of flying through improvement in the aerodynamic characteristics of heavier-than-air craft, without sacrificing the good practical qualities of the present-day aircraft.

Plan of Competition

The Competition will be conducted in accordance with the following plan :—

1 Conditions for Entrance

Application for entry will be received on and after September 1st, 1927. All applications must be made on forms which will be furnished by the Fund upon request. All applications must be forwarded to the Fund at 598, Madison Avenue, New York, N.Y. An entrance guarantee of one hundred dollars ($100.00) must be forwarded with the application, and will be returned upon rejection of the entry or upon the acceptance and presentation of the aircraft for test. Before any aircraft can be tested in the Competition full information as to its design and construction must be supplied to the Fund. The application must be accompanied by a statement giving in so far as possible the information called for in Appendix I., in which the applicant is required to produce evidence as to the aerodynamic characteristics of the aircraft and as to its general suitability for entering the Competition having the object given above. The Fund reserves the right to accept or reject any application for entry and to close the list of entries whenever, in its opinion, sufficient entries have been received to give a reasonable prospect that the object of the Competition will be achieved.

Any heavier-than-air craft based on any principle and built in any country shall be eligible for entry for the Daniel Guggenheim Safe-Aircraft Competition, provided preliminary evidence satisfactory to the Fund is produced that it will promote the object which the Daniel Guggenheim Safe-Aircraft Competition seeks to further. The employment of design features which, in the opinion of the Fund, are copied from the design of another competitor, may render the aircraft ineligible for entry.

2 Qualifying Requirements

Every aircraft whose entry for the Competition has been duly accepted will be called upon to demonstrate that it satisfies all the qualifying requirements which are prescribed in Appendix II. In the case of an aircraft which departs radically from conventional practice in securing flight, the Committee of Judges may substitute for those requirements that are impossible of attainment, other tests that will satisfy the object of the Competition.

3 Safety Requirements

On satisfactory demonstration that all the qualifying requirements are satisfied, the aircraft will be eligible to take part in the Competition proper, consisting of the safety tests and demonstrations in Appendix III.

4 Prizes and Grants

The winner of the Competition will receive a prize of $100,000, which amount will include the safety prize if previously received as provided below.

The winner will be the competitor whose aircraft satisfies the qualifying requirements and all the safety requirements, and is awarded the highest number of points in the four safety tests enumerated in Appendix IV. Should more than

one aircraft win the same maximum number of points, division of the prize will rest within the discretion of the Committee of Judges.

The first five competitors, in the order of presentation of their aircraft for examination and test at the designated field, whose aircraft satisfy all of the safety requirements called for in Appendix III., will each receive a safety prize of $10,000.

The Fund will consider an application for special grants towards the cost of transporting duly accepted entries to the place where the Competition is held, which will be at a flying field in the vicinity of New York City, on the basis of one dollar per mile in excess of 1,000 miles up to a maximum grant of $2,000 for any contestant. This grant will not be made until all the qualifying requirements have been satisfied.

5 *General Conduct of the Competition*

Notification of the result of their applications will be sent to applicants as soon as possible. The Competition will be held at a suitable field in the vicinity of New York City. The examination of the aircraft and the qualifying and safety tests will be held from time to time as designated by the Fund. The tests will be conducted by a Committee of Judges assisted by a Field Manager and Technical Advisers selected by the Fund. Decisions of the Committee shall be subject to the approval of the Fund.

The general conditions under which the tests will be carried out are specified in Appendix V.

6 *Closure of Competition*

The Competition shall be closed on October 31st, 1929, and no aircraft will be accepted for test unless presented for test at the designated field on or before this date.

The Fund may advance the date of the closure if and when in its opinion the object of the Competition has been achieved.

If the date of closure is thus advanced, any contestant whose entry has been duly accepted before the date of the closure thus advanced will be granted a reasonable extension of time in which to present his aircraft.

7 *Proprietary Rights*

The award of prizes shall not entail the abandonment of any proprietary rights on the part of the contestant, but the Fund shall have the right to disseminate complete information pertaining to the aircraft in any way it sees fit.

APPENDIX I.

Information Required with the Form of Application for Entry

1. The name of designer and constructor.
2. Date when contestant will be ready to undertake tests.
3. Three-view drawing.
4. Brief general technical description of the aircraft.
5. Type of engine or engines used, with particulars as to official type trials of such engines and fuel used.
6. Weight estimates and estimates of useful load and volumetric carrying capacity and the horse-power for which same are calculated.
7. Any performance estimates and calculations available.
8. Information and sketches as to power plant installation, seating, vision for the pilot, instruments and controls.

9. Any further information available, including in the case of aircraft involving a radical departure from normal practice in aerodynamic form :—

(*a*) Results of wind tunnel tests or any other data available.

(*b*) Statement as to whether a full scale aircraft of similar type has been flown previously.

In cases where it is not possible to supply the whole of the above particulars when application for entry is made, the fullest information possible in regard to the proposed design should be supplied at the time of making application, and the remaining items of information specified above should be forwarded to the Fund as soon afterwards as possible.

If the applicant desires to withhold any of the above information as likely to divulge valuable secrets, he should give his reasons for withholding the information and the Fund will decide whether such reasons may be considered valid.

APPENDIX II.

Qualifying Requirements

Every aircraft whose entry for the Competition has been duly accepted must be presented for examination and test at the designated flying field on the date designated by the Fund when the tests will be carried out within a reasonable time. Reasonable delay may be granted by the Fund.

Before an aircraft is presented for test the following additional information to that given in Appendix I. will be required :—

(1) Three-view drawing with principal dimensions of important parts.

(2) Dimensional drawings and particulars required for verification of stress analysis.

(3) Stress analysis in accordance with the methods approved for Civil Aircraft by the U.S. Department of Commerce or by any recognised Government Agency responsible for the issue of Airworthiness Certificates, including a statement as to the materials used and the mechanical properties assumed for same. Stress analysis for machines in which sustentation is provided by other means than that of fixed wings shall be required to show a theoretical basis of the strength calculations for the structure as well as the calculations themselves.

(4) Balance diagram.

The following are the qualifying requirements every aircraft must satisfy :—

1 Power Plant

The engine or engines used must be of a type which has been submitted to duly authenticated type tests, full particulars of which must be supplied by the entrant. The horse-power of the engine will be considered to be the rated normal horse-power at full throttle as developed with the same or equivalent accessories used in the type tests, and throughout the tests the r.p.m. of the engines shall be limited accordingly. During the whole of the tests in connection with the Competition the fuel used shall be the standard fuel supplied by the Fund or fuel of the same quality as was employed during the type tests of the engine. The aircraft must be provided with mechanical or electrical means of starting the engine or engines, or alternatively the engines may be started by hand providing a starting gear is fitted which involves no risk of injury to personnel. Starting by direct pulling over of propellers by hand will not be permitted. Any starting gear used will be considered to be a part of the aircraft and must be carried throughout the Competition.

2 *Structural Strength*

The structural strength of the aircraft shall be in accordance with the requirements of the U.S. Department of Commerce Air Regulations. Where a designer has reason to deviate from such requirements an explanatory statement should be submitted with his stress analysis. Copies of the U.S. Department of Commerce Air Regulations and of the method proposed for stress analysis by the Department of Commerce will be furnished on request.

If the contestant contemplates landings made with considerable vertical velocity, computations for strength of landing gear covering this condition should be submitted.

If an aircraft shows structural weakness during the Competition, test of the aircraft may be discontinued at the discretion of the Fund.

3 *Performance*

When carrying full load the aircraft shall satisfy the following minimum requirements in regard to performance :—

Maximum speed (corrected to standard air at sea-level), 110 m.p.h.
Rate of climb (at 1,000ft.), 400ft. per min.

4 *Useful Load*

The aircraft shall carry 5 lbs. of useful load per h.p. "Useful load" shall include the following items :—

Pilot.
Observer.
Fuel.
Oil.
Any special instruments or equipment fitted by the Fund for the purpose of the Competition.

5 *Fuel and Oil*

The aircraft shall provide tank capacity for fuel and oil for three hours at full throttle at the normal r.p.m. as given in the type tests.

6 *Instruments*

The aircraft shall be provided with all necessary power plant instruments required by the engine installation, and the following flying instruments :—

Altimeter.
Airspeed Indicator.

7 *Accommodation*

Adequate accommodation and dual control for pilot and observer. For every 10 lbs. of useful load carried in addition to the items specified under (4) above, there shall be provided at least one cubic foot of cabin or cargo space.

8 *Vision*

Adequate vision must be provided for the pilot.

9 *Fire Risks*

All reasonable precautions against fire risks shall be provided in the design. At least one fire extinguisher of approved type shall be carried and placed conveniently for the pilot; the weight of this shall not be included in useful load.

APPENDIX III.

Safety Tests and Demonstrations

Every aircraft shall be subjected to the following safety tests, which shall be carried out in any sequence the Fund may determine.

NOTE.—The use of devices by which the aerodynamic characteristics of the aircraft can be varied during flight will in general be permitted, subject to the following conditions :—

If the device is not automatic and requires operation by the pilot, the operating control must be simple, quick in action and conveniently placed, and must not involve appreciable physical effort by the pilot. If in the opinion of the Fund the safety of the aircraft is prejudiced by dependence on the operation of such device in emergency, the aircraft may be called upon to pass any or all of the safety tests at one fixed setting of the device, in which case the Rate of Climb Test under "Qualifying Requirements" must be passed at the same fixed setting of the device.

1 Speed Tests

OBJECT : To demonstrate the ability of the aircraft to fly and glide at much lower speeds than is possible in the case of present-day commercial aircraft, thus reducing the risk involved in negotiating forced landings, particularly under conditions of bad visibility and when approaching small and confined landing space.

REQUIREMENTS :

(*a*) *Minimum Flying Speed.*
The aircraft to maintain level and controlled flight at a speed not in excess of 35 m.p.h.

(*b*) *Minimum Gliding Speed.*
The aircraft to be able to glide for a period of three minutes with all power switched off, during which time the air speed shall never exceed 38 m.p.h.

The aircraft will not be considered to have passed either of the above tests unless it is clearly demonstrated that each and all of the controls are properly effective at the minimum speed specified.

2 Test of Landing Run

OBJECT : To demonstrate the ability of the aircraft to effect a safe landing in a small field.

REQUIREMENTS : The aircraft shall land with all power switched off, and after first touching the ground shall come to rest within a distance of 100ft.

The landing shall be made in a straight line; turning, sideslipping or trick flying will not be permitted.

The use of braking devices will be permitted provided that control is fully retained until the aircraft has come completely to rest and provided that no serious injury to the surface of the landing field results.

Such braking devices must not require special equipment which is not carried on the aircraft in flight.

3 Test of Landing in Confined Space

OBJECT : To demonstrate that in case of complete engine failure the aircraft can approach and land in a small confined space surrounded by obstructions, such as trees, buildings, etc.

REQUIREMENTS : The aircraft shall make a steady glide in over an obstruction 35ft. high and land in a straight line with all power switched off. After landing, the aircraft shall come to rest within a distance of 300ft. from the base of obstruction.

The approach to the landing ground shall be straight; turning, sideslipping, or trick flying will not be permitted.

The use of braking devices will be permitted under the conditions set out under (2) above.

4 *Test of Take-Off*

OBJECT : To demonstrate that the aircraft can take off from a small field and after taking off can climb at a steep angle so as to clear obstructions, such as trees, buildings, etc.

REQUIREMENTS :

(*a*) The aircraft shall take off after running not more than 300ft. from a standing start. The aircraft will not be considered to have passed this test if it touches the ground again after taking off.

(*b*) After taking off within a distance of 300ft. from a standing start, the aircraft shall clear an obstruction 35ft. high at a distance of 500ft. from rest. The approach to the obstruction shall be straight and trick flying will not be permitted. External assistance in starting the run will not be permitted in either (*a*) or (*b*).

5 *Test of Gliding Angle*

OBJECT : To demonstrate the ability of the aircraft to glide for a reasonable distance in case of engine failure and alternatively to glide at steep angles in order to facilitate the approach to a possible landing ground.

REQUIREMENTS :

(*a*) *Flattest Glide.*—The aircraft shall be able to glide with all power switched off so that the angle between the flight path and the horizontal is not greater than eight degrees.

(*b*) *Steepest Glide.*—The aircraft shall be able to glide with all power switched off so that the angle between the flight path and the horizontal is not less than 16 degrees. During this test the air speed shall not exceed 45 m.p.h. In both cases the aircraft must demonstrate that all the controls are definitely effective throughout the test, and that it can land safely out of this glide from a useful altitude.

6 *Test of Stability in Normal Flight*

OBJECT : To demonstrate that the aircraft is stable under all normal flying conditions, that is to say that if the attitude of the aircraft is disturbed either by gusts or by the application of the controls, the aircraft shall return to its original attitude of its own accord when the controls are left free.

REQUIREMENTS :

(*a*) *Longitudinal Stability.*—The aircraft to be provided with means by which it can be trimmed so as to fly with the elevator control free at any speed within the range of 45 m.p.h. to 100 m.p.h. and at any throttle opening of the engine or engines. The test of longitudinal stability shall be as follows :—The elevator control to be moved towards its maximum extent either backwards or forwards sufficiently to give a fair test of stability and then released. In either case the aircraft must return to steady flight in its original attitude within a reasonable time.

(*b*) *General Stability.*—The aircraft to be capable of flying at any air speed from 45 m.p.h. to 100 m.p.h. and at any throttle opening of the engine or engines with all controls left free for a period of not less than five minutes in gusty air.

In the case of a multi-engine aircraft, all the engines may be throttled to the same extent.

During any of these tests the aircraft must hold a reasonably steady course, and if disturbed from its normal attitude, must return to such attitude within a reasonable time and without losing height appreciably.

7 *Test of Ability to Recover from Abnormal Conditions*

OBJECT : To demonstrate the ability of the aircraft to recover from any attitude into which it may get either because of disturbances in the air or of incorrect application of the controls by the pilot, or of sudden failure under difficult circumstances.

REQUIREMENTS :

(*a*) *Test of Ability to Maintain Control in Case of Engine Failure.*

The aircraft must demonstrate that it can be satisfactorily controlled by the pilot in case of sudden engine failure when flying at any attitude. In case of multi-engine aircraft, the pilot must be able to maintain control when any one of the engines or any combination of the engines or all of the engines suddenly fail.

The aircraft will be required to demonstrate that in case of complete engine failure (all power being switched off) it will take up a steady gliding attitude when all controls are left free from the moment of switching off the engine or engines.

The aircraft will further be required to demonstrate that if the elevator control is pulled in towards its maximum extent at the moment of switching off and held in that position, the aircraft will remain under control, not get into any violent or dangerous manœuvres, and descend on a steep glide path at a speed not exceeding 40 m.p.h.

(*b*) *Test of Ability to Recover from Violent Disturbances.*

1. The aircraft to be dived with all power switched off until air speed reaches 20 per cent. above maximum level flying speed. At this speed it must answer all the controls correctly and effectively. All controls will then be released and the aircraft must of its own accord return to a steady gliding attitude without serious loss of height.

The aircraft may be required to pass this test when trimmed for any speed from 80 m.p.h. to 110 m.p.h.

2. The aircraft to be flown at full throttle at an air speed of 45 m.p.h. trimmed for any speed from 45 m.p.h. to 75 m.p.h. The engine is to be switched off, and at the moment of switching off the pilot is to move any one or any two or all of the controls in such manner that an abnormal attitude results. Complete recovery is to be made with the aid of the controls and a steady glide to be taken up with a loss of height of not more than 250ft. from the height at which the abnormal flight attitude was obtained.

The same test is repeated with the exception that when in an abnormal flight attitude, all controls are to be released, and the aircraft must make complete recovery of its own accord and take up a steady gliding attitude with a loss of height of not more than 500ft.

8 *Test of Controllability*

OBJECT: To demonstrate that the control system is simple and easy to operate, and that under all conditions of flight and gliding, effective control in all senses is maintained. Every aircraft must be equipped with three substantially independent controls corresponding to three axes mutually at right angles, and these three controls must continue to be substantially independent and collectively effective in the same direction at any attitude of the aircraft from the attitude at maximum level flying speed to the attitude at the steepest glide and at any throttle opening of the engine or engines. The aircraft must clearly demonstrate that it is not subject to complete loss of control when any particular attitude is reached, such as the loss of control which accompanies the phenomenon of stalling.

REQUIREMENTS: The aircraft will be required to demonstrate the effectiveness of each and all of the controls at any speed and at any attitude from the attitude at maximum level flying speed to the attitude at the steepest glide and at any throttle opening of the engine or engines. This will be tested by making definite and sharp movements of any particular control or controls, which must result in the aircraft making corresponding definite rotations about the respective axes. The controls must not only be effective in producing disturbances of attitude, but also in enabling rapid and definite recovery to be made from disturbances.

The effectiveness of any one control or combination of two controls when the other control or controls are left free or held in fixed position must be demonstrated.

The aircraft may be called upon to pass these tests in calm or gusty air.

9 *Test of Manœuvrability in Restricted Territory and on the Ground*

OBJECT: To demonstrate that the aircraft can be safely and effectively manœuvred when taking off or landing in restricted territory and when taxying on the ground under its own power without external assistance.

REQUIREMENTS:

(*a*) *Manœuvrability in Restricted Territory.*

A square plot, 500ft. by 500ft., will be marked off and shall be considered as surrounded by an obstruction 25ft. high along its entire boundary. The pilot shall take off in any manner he judges best, and climb either above the square plot or outside of it, providing he passes above the imaginary boundary obstruction. The engine may be switched off at any time and the pilot shall land the aircraft within the square plot without passing through the imaginary boundary obstruction.

(*b*) *Manœuvrability on the Ground.*

The aircraft will be required to demonstrate that it can be taxied under its own power and without external assistance in any direction in a wind whose mean speed at ground level is at least 20 m.p.h.

The aircraft will also be required to demonstrate that it can be easily handled and moved by ground personnel as required of any aircraft operating for commercial purposes.

APPENDIX IV.

Basis for the Award of the Prize

Points will be awarded as specified in the four following tests :—

	Maximum No. of Points obtainable.
1 Speed Tests	
(*a*) Two points for every m.p.h. less than 35 m.p.h. at which level controlled flight can be maintained	10
(*b*) Four points for every m.p.h. less than 38 m.p.h. which is not exceeded in a steady controlled glide during a period of three minutes	24
(*c*) Any aircraft which obtains a combined total of at least 24 points under tests (*a*) and (*b*) will be eligible to receive points for high speed in excess of 110 m.p.h. as follows :— One point for every 2 m.p.h. in excess of 110 m.p.h. at which level flight can be maintained	10
2 Test of Landing Run	
Two points for every 3ft. less than 100ft. in coming to rest after first touching ground	40
3 Test of Landing in Confined Space	
One point for every 2ft. less than 300ft. from the base of an obstruction 35ft. high in coming to rest after gliding in over the obstruction	75
4 Test of Take-Off	
One point for every 15ft. less than 300ft. required to take off from standing start	15
One point for every 10ft. less than 500ft. to clear obstruction 35ft. high from a standing start	26
	200

APPENDIX V.

General Conditions

1. Contestants shall comply with the Rules laid down by the Field Manager in regard to all work and conduct on the field.

2. Aircraft shall be kept at the designated field throughout the Competition unless special authority for its removal is obtained in writing from the Field Manager.

3. Aviation fuel of standard quality will be supplied free of charge, but another fuel may be used provided such fuel was used in the official trials of the engine or engines employed.

4. Prior to any tests made by the Fund, contestants may be required to demonstrate in flight by their own pilot that their machines are airworthy and provided with proper controls.

5. All tests in the Competition will be carried out by pilots supplied by the Fund, but contestants shall be given reasonable opportunities for instructing

the Fund's pilot in the flying of their aircraft prior to the commencement of the tests.

6. Contestants shall supply their own mechanics and transport, and prepare and maintain their aircraft during the Competition at their own expense.

7. The Fund will accept no liability at any time in connection with any risks involved to the aircraft or to the contestant's personnel, or in connection with any third-party risks involved when the aircraft is being flown by the contestant's pilot.

8. The contestant will not be held liable for injury to flying personnel representing the Fund.

9. The Fund may at any time suspend temporarily or permanently any aircraft from taking further part in the Competition if, in the opinion of the Fund, danger to flying personnel is involved, or the object of the Competition is not likely to be furthered by proceeding with tests of such aircraft.

10. Contestants shall be allowed at least three fair attempts to pass any test.

11. Alterations to the aircraft during the Competition may be approved, but any such alteration may entail requalification in any or all of the tests at the discretion of the Fund. Unauthorised alterations may entail elimination from the Competition.

12. Variations in the form of features of the aircraft which cannot be conveniently and easily effected by the pilot during flight—as, for example, variations in angular settings of supporting surfaces—will be regarded as alterations.

13. The same design of propeller shall be used throughout the trials. In case of propeller breakage or damage a new propeller of identical design may be substituted. Propeller blade settings must be the same throughout the test, except that a pitch-varying mechanism may be used if it can be operated from the pilot's cockpit during flight.

BRANCHES

YEOVIL BRANCH

Paper read before the above Society at the Sixteenth Meeting for prospective Ground Engineers, held at 7.30 p.m. at the Mermaid Hotel, Yeovil, on February 23rd, 1927.

METALS AND THEIR HEAT TREATMENT

BY S. G. WILLIAMS, ESQ., A.M.I.M.E., A.I.D.

Mr. Williams remarked that the modern tendency in engineering is to endeavour to heat-treat the existing metals to enable them to withstand the stresses induced by modern design.

Many similar metals are used as in days gone by, but the modern steels are alloyed with other elements to enable them, with particular treatment, to give much higher strength results. For these alloy steels and also for the lighter alloys, special precautions have to be observed in their manufacture, whether they are destined for automobile or aeronautical work, although with aircraft work more precautions are necessary than in any other class of manufacture.

To understand the effect of heat treatment it is necessary to know how the structure of a steel is influenced by heat treatment.

In the typical crystal formation for steel it can be seen that there is a definite dark line or boundary surrounding each crystal. If any impurities are present they gather around the crystal, and cracks will often be found to commence at these boundary lines if the process of manufacture or heat treatment has been defective.

The crystalline structure demonstrates whether the heat treatment has been correct or not. After rolling, it will be noted that the crystals become flattened or crushed, showing that the metal has a plastic nature capable of being deformed, the crystals becoming elongated.

The most commonly used steel for the work under review is an original carbon steel, which is divided into two classes containing .20 to .30 carbon, and .30 to .40 carbon.

In .35 carbon steel in the normalised condition it will be noted that the white area representing the original iron has become reinforced by small patches of carbon-plus-iron known as pearlite. All the effects to be observed in the heat treatment of carbon steels are associated with what happens to this pearlite. The pearlite is so called because of its pearly appearance under the microscope.

The process of normalising is resorted to in order to induce the best mechanical tests from a piece of steel by good distribution of the pearlite. There must be no segregation. The white area has the strength of iron probably 18 tons per square inch, whilst the black area, pearlite, has the strength approaching that of tool steel, so that a properly normalised steel of this structure should have an average strength of 35/45 tons per square inch.

The normalising treatment consists of heating in a closed muffle at 860°/880°C., soaking for 5/15 minutes according to size, and cooling in still warm air near the muffle. The time of soaking must vary according to mass, but thin steel sheet need not be soaked for longer than five minutes.

Mild carbon steels of the S.1, S.6 type in the normalised condition should have a Brinell hardness of approximately 150/210. As a general guide it should be noted that the temperature varies inversely as the carbon content.

Thus—carbon content .10—normalise 900°C.
,, ,, .40 ,, 860°C.
,, ,, .60 ,, 850°C.

For brazing it is possible to combine the two operations; thus by dipping the material in a bath containing molten brazing spelter at a temperature of 860/900°C. it is possible to effect the desired bond and the normalising at the same time. Sufficient time must be allowed in the bath to permit structural changes to take place in the material, in addition to the simple brazing operation.

At a magnification of 1,000 of a patch of pearlite the laminated formation can be clearly seen. The temperature which produces such a structure as this is most important: 780° to 820°C. may be the critical temperature, and to ensure that the steel is heated past this critical range the temperature should be 850-880°C.

It is not possible to have a very close limit because obviously the temperature of the furnace is subject to variations, as are also the temperature measuring instruments.

The changes in carbon steels are the same as in alloy steels, but in the latter case it is not so easy to show up the structure by micro-photographs.

Alloy Steels

The common alloy steels are usually nickel or nickel chromium steels. The steel maker makes up standard steel with carbon of about 0.25 to .35 per cent. and then adds about $3\frac{1}{2}$ per cent. of nickel and one per cent. chromium.

Specifications such as S.11, S.2, K.1, K.33 are from steels of this class, and the more important moving parts of aero engines are made therefrom. In addition, the new steel strip which is now coming into use is from this class of material.

The qualities and treatment necessary are now becoming definitely known, and it is more than probable that the S.11 type of alloy steel will be used in greater quantities in future.

The process of treatment involves heating the material, causing the crystal boundaries to disappear, thereby producing a state of solid solution. This occurs at a temperature of 820°C. and the steel is then plunged into oil in order to "freeze" the structure in this condition. So quenched, the strength may be about 80/100 tons per square inch and is too hard; it therefore has to be tempered. Most alloy steels are treated in this way, but the actual temperature given above may be varied from 810° to 840°, according to the class of steel, that is, according to its carbon content. If this is not known, 820° is a good all-round figure to use.

In order to temper this material it should be reheated to about 580-600°C. according to the mechanical tests required. For example, 640-650°C. is a good figure, and steel so treated will have a strength of 60 to 65 tons per square inch, and an impact value of about 50 ft. lbs.

The two tests, however, *i.e.*, tensile and impact, are always at loggerheads, so it is necessary to choose the temperature according to the needs of the part. The impact test is very necessary in order to show up any fault in the treatment. The tensile test shows that the first hardening process has been satisfactory. If the impact test gives a low figure, then that shows that the tempering temperature was not sufficiently high.

The tensile test gives the simple strength values, whilst the impact test shows the toughness of the material.

If the temperature is too high, a greater toughness is obtained but insufficient tensile strength. To sum up, we should use 820° for hardening temperature and

650°C. for tempering. The latter can be varied slightly to suit the tests desired. The only workshop test is the fracture test, but this is not so reliable as the impact test.

It is possible to reproduce the impact test by using a hammer and vice in the following manner. Cut the specimen lightly with a hacksaw. Hold in a vice and break with a hammer. A quick brittle fracture indicates a low impact value. Bending and difficult breaking indicate toughness.

The Brinell hardness test correlates directly with the tensile test. It is the measure of comparison between a specimen test piece and the remainder of the material. This test is necessary for the accurate control of any heat-treatment operations. It should be used to indicate the efficiency of the various phases of the heat-treatment process; thus the success of the quenching operation should be determined by occasional Brinell hardness tests.

A temperature of 550° to 650° is the best all-round tempering temperature, producing in the material a strength of 50 to 60 tons per square inch.

Martinsite is a needle-like formation of the crystals. A tiny crack tends to develop due to incorrect heat treatment.

These crystals are like packs of cards, and in the working there is a tendency for them to slip along each other. The material then splits under pressure along the lines of the needles. The slide (not printed) shows martinsite, but with a much finer structure. This slide is taken at a 250 magnification, which is a good size for examining the structure. Further inclusions will be noted here, particularly manganese sulphide. The trouble is that these inclusions tend to run in lines. During forging there is a tendency for cracks to develop along these lines of inclusions.

The following slide (not printed) shows steel heated to 820°C. and then plunged into cold oil. It will be noted that cracks have started. If this was the ordinary commercial steel these defects might not be discovered, and it is only the very careful examination which ensures freedom from defects. This examination must be done at an early stage of manufacture, hence the numerous inspection processes adopted by steel manufacturers. They save machinists trouble, and prevent expense in the long run. In many cases where cracks develop on such a part as a connecting rod the steel makers will blame the heat treatment, whilst the man who performed the heat treatment will blame the steel maker, and the only way to check is to ensure early examination of the material at each stage of manufacture.

All this shows the need for care at every stage of manufacture. Every care must be bestowed upon the various details of each process. Temperatures must be accurately measured. The operator must be sure that he has the temperature of the work and not merely that of the furnace. It is desirable at times to place the thermo couple actually upon the work itself.

To determine the heat treatment necessary to produce a required series of mechanical test values, the following first principle may be adopted. Ascertain the composition from identification marks, steel maker or analysis. Three test specimens should be prepared suitable for tensile, impact and Brinell test from the one piece, say, 12in. long by 1in. diameter. The method to be adopted is really to take three sighting shots in the region of the tempering temperature suspected as being suitable. A standard hardening temperature can be used for these eliminating tests.

If the material is thought to be standard alloy steel of the S.11 type, oil quench the three pieces together from 820°C. Then proceed to temper them separately at, say, 550°, 600°, 650°C. The specimen should then be tested by Brinell, and if found satisfactory the complete series, tensile and impact tests, should be taken.

The treatment for carbon steels may be determined in the same manner. It is desirable to adjust the hardening temperature in sympathy with the carbon

content. The temperature falls as the carbon rises. The approximate limits of the range are :—

Carbon .20 per cent., quench 850°C.
Carbon .80 per cent., quench 760°C.

Heat Treatment of Aircraft Alloy Steel.—Specification S.11, S.33, K.1, S.2 and S.28.

This material is a standard nickel chrome steel which is largely used for important components. The general type of composition is :—

Carbon, .20 to .35 per cent.
Nickel, 2.50 to 4.00 per cent.
Chromium, 0.50 to 1.50 per cent.

The lower carbon is favourable for forging. The higher nickel and chromium permit somewhat higher mechanical tests. They also ensure air-hardening if that is desired.

The range of mechanical tests for this steel is :—

Tensile test.
Ultimate stress, 50 tons to 100 tons/sq. in.
Elongation, 25 per cent. to 5 per cent.
Izod impact, 80 ft. lbs. to 10 ft. lbs.
Brinell, 230 to 450.

This range of mechanical properties provides the base for many specifications which use the one mother material but develop the various properties required by means of heat treatment. The general material is S.11, which is at the mean of the physical properties, thus combining the best from each direction. Thus we obtain the highest toughness and ultimate stress.

The range of test figures usually obtained on S.11 material is :—

Yield stress, 45/55 tons sq. in.
Ultimate stress, 55/65 tons sq. in.
Elongation, 18/24 per cent.
Reduction of area, 50/55 per cent.
Izod impact, 40/70 ft. lbs.
Brinell, 245/295.

The above values may be obtained by the following treatment. The temperature for quenching is constant. All adjustments must be made by variations in the tempering temperature.

Harden.—Soak 820/830°C. for 15, 30 or 60 minutes. Quench in cold oil.
Temper.—550/650°C. few minutes. Quench in oil or water.

The lower tempering temperature will give the higher tensile value, but a lower impact test figure may be obtained. The longer soaking time of 30/60 minutes would be suitable for such a mass as an aircraft engine connecting rod.

The air-hardening alloy steels are obtained by keeping the nickel and chromium at the maximum. The advantage of this type of steel is the absence of possible distortion or cracking, and the ability to dispense with the quenching operation.

A typical ordinary air-hardening composition is :—

Carbon, .35 per cent.
Nickel, 5.00 per cent.
Chromium, 1.50 per cent.

Harden.—Soak 820/830°C., cool in cold air, preferably in a draughty situation.

Temper.—550/650°C. Quench in oil.

Similar physical properties will be obtained as for the standard type steel.

100-ton steel is obtained by selecting a nickel-chrome-carbon composition of maximum range :—

Carbon, 0.35 per cent.
Nickel, 5.00 per cent.
Chromium, 1.50 per cent.

Heat to 790/800°C. Cool in air.
Temper, 250°C. for about 15 minutes.

This low temperature operation is important, and ensures relief of the stresses due to first cooling and improves the toughness.

Test values for this treatment can be :—

Ultimate stress, 100 tons sq. in.
Elongation, 18 per cent.
Reduction of area, 25 per cent.
Izod impact, 12 ft. lbs.
Brinell, 444.

All steels after preliminary heat-treatment operations are improved by this low tempering. It improves the Izod test without reducing the tensile test value.

A special type of air-tempering steel is the molybdenium alloy steel composition similar to the following :—

Carbon, .30 per cent.
Nickel, 2.50 per cent.
Chromium, .50 per cent.
Molybdenium, .60 per cent.
Harden.—Soak 820/830°C. Quench in oil.
Temper.—550/650°C. Cool in air.

This type of steel is not subject to temper brittleness, and does not require quenching after the final tempering operation which is necessary for all the standard alloy steels.

Three optional alloy elements which may be added to the standard nickel chrome steel are vanadium, tungsten and molybdenium. These are added according to the private practice of the particular steel works. The quantity is usually up to one per cent. of any one. They are not added in combination. The steel maker is always a specialist in a particular line and likes to have a brand for which he claims all the virtues. The basis of these brands is usually a manipulation of the usual elements.

Stainless steels may be divided into two types—(1) chromium, (2) chromium nickel.

(1) Plain chromium type.
Chromium, 14.00 per cent.
Silicon as low as possible.

This is the original type and has a considerable field of usefulness. There are certain claims made that it is not entirely stainless. This may be in part true, if the material is not in the ideal condition.

Heat treatment :—
Harden.—900°C. Quench in oil.
Temper.—750/780°C.

Steels of this type are inclined to lose toughness rapidly when the ultimate stress exceeds 52 tons sq. in. Normal values are :—

Yield stress, 45 tons sq. in.
Ultimate stress, 50 tons sq. in.
Elongation, 20 per cent.
Reduction of area, 50 per cent.
Izod impact, 45 ft. lbs.

(2) Chromium nickel type.

This material has been developed as the "Staybrite" brand by Messrs. Firth, Sheffield.

Chromium, 18.00 per cent.
Nickel, 10.00 per cent.

The physical properties are similar to the above, except that they cannot be changed after leaving the steel maker. This is owing to the exceedingly high temperatures necessary for the quenching operation, and the fact that the hardness is due to mechanical work and not to the operations of heat treatment. The steel is of the type known as "Austenitic."

The peculiarity of these steels is that they are soft after quenching in water from about 1400°C. This is due to the fact that Austenite is soft and can be retained in that state by rapid freezing. The only subsequent treatment possible is to temper at 750/800°C. This could be used as a normalising operation to release stresses due to work, should such treatment be regarded as necessary to meet a special need.

Heat-resisting steel can be obtained containing high nickel and chromium.

Composition :—
Nickel, 25.00 per cent.
Chromium, 12.00 per cent.
Tungsten, 3.00 per cent.
Yield stress, 35 tons sq. in.
Ultimate stress, 45 tons sq. in.
Elongation, 30 per cent.
Reduction of area, 40 per cent.
Izod impact, 40 ft. lbs.

This steel retains its strength at a considerable temperature. It is useful for values and parts subjected to great heat. The material is Austenitic and consequently cannot be influenced by heat treatment.

Manufacture

So far the master type alloy steels and the heat-treatment faults have been touched upon, and we will now consider the process of manipulation at the steel makers' works.

1. Rectangular ingots may be somewhat like a coffin both as regards size and shape, and in casting it is inevitable that, due to the scum, etc., the top portion of the ingot is bad, whilst the bottom portion is not entirely good. For aircraft purposes only the best portion of the ingot is used. This occurs at about two-thirds of the distance down. For this reason it will be understood why aircraft steels are more expensive than those suitable for other purposes.

The top of the ingot is cut off, then the piece at the bottom, so that out of the original length of 6ft. only about 3 or 4ft. remains, but even this is liable to have faulty metal in the core. It is therefore sometimes cut up so as to eliminate the central portion, leaving two slabs or cheeks for large material, whilst for smaller bars the ingot is quartered, so producing four square sections suitable for rolling to smaller sizes.

Forging effects.—The slide (not printed) shows the lines of flow in a crankshaft forging. This is the ideal structural formation, and although it is expensive, modern crankshafts in many cases are forged in this way. The next slide shows a valve forging, and here again the lines of viscous flow can be clearly seen. The steel is forged at 1100 to 1200°C., which renders it plastic, hence this ideal structure.

Overheating.—In overheating it will be noted that the crystals show a tendency to revert to the primitive iron, the alloying elements having become

segregated ready to find their way out along the crystal boundary lines. Gas ducts are liable to be formed due to carbon seeking the oxygen, and if the overheating was persisted in, the finished material would be practically pure iron. An area of iron is produced by decarburising a case-hardened steel by overheating and improper care. It is necessary to work as closely as possible to the safe temperature range.

Testing.—In order to examine the material to see the effect of the particular heat treatment it is necessary to have test pieces. These test pieces are not merely separate pieces treated alongside the actual article, but are wherever possible a portion of the article itself.

The next slide (not printed) shows a crankshaft with an extension piece at the end, which it will be seen is large enough to give two tensile and two impact test pieces. One each of these test pieces would first be used, and the others only tested if the results of the first test were such as to make reheat treatment advisable.

Light Alloys

I should like now to deal with metals other than steel, although the same theories apply to light alloys as those mentioned for steels. Light alloys comprise duralumin and "Y" alloy; this is slightly different from duralumin. Another alloy which is coming into general use is magnesium alloy.

Duralumin consists of aluminium plus a small percentage of copper, magnesium, silicon and manganese. It has recently been suggested that magnesium and silicon are the most important constituents, having similar effects to those of carbon and steel.

Heat treatment.—The approximate temperature to which duralumin should be heated is 500°C., although in the laboratory it may be possible with suitable precautions to work to 510°C. In order to ensure uniform heating a salt bath is used. The metal is then plunged in water, but the curious fact about duralumin is that it does not then harden. What is known as age-hardening takes place, and this is now being investigated more and more. Probably what actually happens is something like this. A change takes place which produces a certain "leven" which gradually disperses and produces hardening after a lapse of time at atmospheric temperatures.

The quenching, it will be noted, has taken place whilst the material is in the state of solid solution, and yet the result of this is not fully attained until some time has elapsed. By means of X-ray analysis and study of the atomic structure we are now just beginning to understand something of this age-hardening. From a strength of 18 tons per square inch the material after treatment finally attains a strength of 26 tons per square inch.

Duralumin is an aluminium alloy of the following composition :—

Copper, 4.00 per cent.
Manganese, .60 per cent.
Magnesium, .60 per cent.
Aluminium, 94.00 per cent.

An improvement of mechanical properties can be obtained by the following heat treatment. This material is subject to the delay hardening phenomenon known as "age-hardening." Thus a piece of metal does not immediately show the maximum result from a given treatment. A period of days must elapse before the complete change has taken place. The effect appears due to a delayed action in the internal arrangement of the structure. A diffusion continues in a normal atmospheric temperature, similar to a tempering operation.

There are two common treatments for duralumin—(1) normalising, (2) annealing.

(1) Normalising produces the best mechanical test result, *i.e.*, about 26 tons tensile and 12/15 per cent. elongation, for bars, sheets and forgings.

It consists of heating to an accurately measured temperature of not exceeding 500°C. and quenching in cold water. An initial softness occurs before the first evidence of hardening appears one hour later, but the metal does not become hard enough to prevent any reasonable bending to be carried out. An appreciable hardening takes place after 24 hours, but acceptance tests should not be conducted until after four to seven days, when the metal has practically reached its finally hardening condition.

(2) Annealing is used to reduce the material to its softest condition prior to manipulation. The treatment consists of heating to 350°C. for at least fifteen minutes and quenching in cold water. Only slight traces of age-hardening have been detected, consequently the material remains in a condition suitable for mechanical work for long periods. The material in this condition gives tensile test values of 12/18 ton sq. in. tensile and 15/20 per cent. elongation.

Annealed material can be restored to the higher mechanical condition by means of the normalising operation. It is generally desirable to use these two operations in series, but in cases of urgency where little manipulation is carried out it is possible to use the normalising operation only, making sure that the bending is carried out within a period of one hour.

Duralumin rivets are best used in the annealed condition. An extra period of soaking is necessary if maximum softness is required. It is further possible to soften harsh rivets by a thorough annealing followed by the usual normalising operation.

The usual method of working with normalised rivets is to arrange continuous supplies of rivets so that fresh supplies are available every hour. It is found that rivets should not be worked much longer than one hour after normalising.

" Y " *Alloy.*—This is similar to duralumin with the addition of nickel. There is 4 per cent. copper, 2 per cent. nickel, and some magnesium and silicon. To compare it with duralumin I would explain that duralumin is similar to the wrought iron of 100 years ago, whilst " Y " alloy is by comparison the mild steel of to-day. In other words, duralumin is more fibrous, while " Y " alloy is the cleaner structure.

Investigators at the N.P.L. have shown how to make the structure cleaner, and the resulting material was named " Y " alloy because it was the result of a series of experiments each of which was given a letter and " Y " was the particular experiment which proved successful. Forged pistons are made from this material, but there is likely to be an ever-increasing use.

" Y " Alloy.—Composition :—

Copper, 4.0 per cent.
Nickel, 2.0 per cent.
Magnesium, 1.5 per cent.
Silicon, .5 per cent.
Aluminium, 92.0 per cent.

This material can be forged, worked in the same manner as duralumin. A particular advantage consists of the absence of the fibrous condition of the fracture, caused by local lamination or discontinuities.

The " Y " alloy has a clean fracture without trace of unsoundness. It is subject to age-hardening, which can be influenced by means of low temperature tempering. The usual heat treatment consists of heating at 520°C. for about 3/4 hours, quench in boiling water. A period of 3/4 days should elapse to permit age-hardening, when full tensile test values will be obtained.

A low tempering for two hours at 200°C. can be made to take the place of the age-hardening to permit immediate testing. After this treatment tensile test values on forged bars will be 26 tons sq. in. tensile, 15/20 per cent. elongation.

This metal is suitable for bars, sheets and forgings. It is used with great success for high duty pistons and connecting rods.

It has been found that heat-treated pistons do not become annealed during engine running. This is because no important structural change takes place in the alloy until a temperature of 300°C. is exceeded. The annealing temperature for "Y" alloy is 350°C.

The Germans have produced an alloy called Lautal by adding silicon to duralumin in proportions round about 2 per cent., and have got astonishing results. They have been able to influence the age-hardening process; in fact, by preliminary heat treatment the material can then be plunged into boiling water and hardened. Silicon and magnesium together produce a constituent which affects this process.

Lautal is a German variation of duralumin. The composition is standard except for the silicon, which is increased to 2.00 per cent. The effect of the alteration is to restrain the age-hardening.

The heat treatment is carried out as follows:—

Anneal.—490/510°C. 15 minutes. Quench in cold water. This gives maximum softness.

To produce hardness and higher ultimate stress values, it is necessary to follow the quenching treatment with a prolonged low tempering, *i.e.*, 16 hours at 120/130°C. It is necessary to use an oil bath to obtain this temperature accurately. Maximum hardness is produced by treating for 48 hours at 140/150°C.

The range of physical test values possible from this series of treatment corresponds to ordinary duralumin. The advantage is due to the case-hardening from the soft condition in which the material is worked. Distortion is practically absent. Material of this type will have a considerable future. The fibrous structure associated with ordinary duralumin is entirely absent.

The influence of these experiments has all been to increase the radius of the heat treatment. As a matter of interest it may be mentioned that a name is badly required for this material as duralumin is no longer explanatory. The name duralumin was apparently decided upon after a member of Vickers' staff had seen it in France, for they there describe hard steel as "Dur-acier," and for hard aluminium they use the term "Dur-aluminium." He therefore had the happy notion of combining the two words, hence "Duralumin."

Magnesium.—A great deal of future aircraft development depends on magnesium alloy. This is a metal which has nearly the strength of duralumin but only two-thirds of its weight. The specific gravity of duralumin is 2.8, whilst that of magnesium alloy is 1.8. In France this material is available, but there are no sources of supply in England. In Germany the magnesium alloy is called electron. These are 90-95 per cent. magnesium plus aluminium. When forged they have a strength of 20-25 tons per square inch and are little more expensive than aluminium alloys. Much has been said about the inflammability of this material, largely due to the fact that magnesium in the form of a fine ribbon is used by photographers for flashlight work.

The magnesium alloys are not influenced to any marked degree by heat treatment. Their particular usefulness is due to light weight; the specific gravity is 1.8. The most promising alloy consists of:—

Magnesium, 94.0 per cent.
Aluminium, 6.0 per cent.

They are suitable for casting or forging. The casting has a tensile of about 9 tons sq. in. The forged condition gives much higher mechanical tests, according to the amount of work carried out. It is possible to obtain 20 tons sq. in. and 10 per cent. elongation. The pure magnesium does not give very high test figures, so that 8/10 tons sq. in. tensile is all that should be expected from the unalloyed metal. Magnesium, like aluminium, is subject to corrosion if not

properly protected. Precautions must therefore be taken to ensure proper protection. Varnish, oil or paint will serve to prevent surface corrosion. This series of alloys will exercise considerable influence upon the future development of light machines from which high efficiency with low weight factor is required.

It is quite true that the naked light must be kept away from shavings. The greatest trouble with this material is its liability to corrode and finished parts must be protected by oil or varnish. Artificial limbs are now being made of this material almost entirely. In addition, the automobile industry is using a large amount of it for racing cars, parts such as pistons and connecting rods having also been made from it.

Failures in service are ever the disappointing feature of engineering design and construction. Apparently perfect structures develop defects without warning. These can be reduced to a minimum by care and experience. Retention of fundamental types of structure is the best help to experience. The unknowns become reduced by elimination.

Material defects must be regarded as accidents which are ever possible, but that their occurrence is made more possible when the cost of production is forced down and essential precautionary processes eliminated. Standard materials in daily production according to their type and quality are usually safest, as the manufacturers become conversant with their particular difficulties. This can be summed up as "one model—one metal," which provides a fundamental equation representing a minimum possibility of failure for any given period in design.

Fatigue.—Fatigue is one of the great difficulties we are up against in all highly-stressed parts of modern engineering and in aircraft particularly. Fatigue indicates that the part has outlived its useful life, and much investigation has been done and is being done to ascertain how to prolong this life.

Fatigue is the usual cause of breakdown. This can be readily identified by the radial lines upon the fracture. These are due to the alterations of stress which have taken place. The unfortunate feature of fatigue is that it sets in at stresses below the normal elastic limit.

The normal idea of the strength of a material is based upon an aggregate by an estimation of the structure as a whole. This mass strength does not protect it against failure by fatigue.

Fatigue is caused by the continuous operation of stresses upon a particular plane. It resembles the nibbling of a mouse in its persistence. The stress seeks for and finds a place in the mixed formation of the material for the initial breakdown. Once this point is located all the stresses become concentrated there, and failure is only a matter of time. The fatigue range of a material may in general terms be indicated as one-half its ultimate tensile strength. Ductility and toughness do not ordinarily enter into its calculation, though these properties must be present to guard other flanks. In consequence of this theory of fatigue it is desirable to keep the ultimate tensile strength as high as possible, whilst ensuring the necessary toughness. All these forces are harnessed by the heat-treatment operation.

A romantic and tragic impression of the possibility of failures can be gathered from the adventures during the war of Major McCudden in his book *Five Years in the R.F.C.* An oft-recurring phrase in the book is "that something broke." The final tragedy is that this successful fighter loses his life for a simple engine failure near his aerodrome, which resembles the acrobat who breaks his neck by falling out of bed.

Conclusion

The whole question of metals and their successful heat treatment is closely associated with the human factor. Many scientific appliances have been intro-

duced to replace so-called guesswork, but the skill and judgment of the craftsman still makes or breaks the job.

The willingness to take infinite pains is the essential qualification and the secret of the successful operations. This was really the carefully guarded secret of the ancient craftsman, who used to pretend to weave a magic spell over crucible and furnace for the benefit of the onlookers.

The actual methods of to-day have made but slight advance. It is the production that has developed. The science of metals depends before everything else upon first principles. Any difficulty should be first met with a review of the simple forces which are operating. Nature is a hard foe to fight against, so that it is much better to have her as an ally. Find out the natural tendency of the operation which is causing the trouble.

Further, it is not sufficient to merely go through the operation of heat treatment leaving the result to luck. Every detail of the process must be ensured to a known degree of accuracy. Full allowance must be made for this error and every attempt made to keep it on the safe side.

Thus all the functions of hardening and tempering can be better carried out if ideal temperatures are worked to. The quenching oil is often not cold enough towards the end of a day. The quenching water would be better if given a cold brine circulation from a refrigerator. The pyrometer should record the temperature of the work instead of the flames. The steel is becoming cool before reaching the oil. It is not good practice to drop hot steel parts into a puddle caused by a leaky roof. It is always worth while to take a Brinell test to see what is happening.

Fatigue failures can be diagnosed by examination of the structure of the fracture. There are always a number of curved lines, and the focal centre of these lines indicates the point about which the fatigue has occurred.

In the next slide it is obvious that the oil hole in this article is the centre of the fatigue curve lines. Large radii of fillets are necessary to prevent sudden changes in section, as such sudden changes are very prone to produce fatigue failures. Similarly, faults in heat treatment will help to promote fatigue failures.

All steel should carry accurate identification marks, so that no doubt can exist as to its composition. The specification symbol should appear on all material as a birth certificate. The small cost of this marking is amply repaid by the confidence it gives to the staff in general and the heat-treatment shop in particular.

All these points go to show that a little knowledge and a lot of care are the only things necessary for successful heat treatment.

Discussion

Captain Keep opened the discussion by stating he agreed how necessary it was to limit the temperature of the furnace and to know that the temperature taken was that of the article and not merely that of the furnace. In the electric furnace which we use he pointed out that we took the temperature up to just beyond that required and then switched off and so caught the furnace at the right temperature on the down grade. Captain Keep asked why it is that "Y" alloy is not more generally used, and whether there are any difficulties in forging it.

Mr. Williams answered by stating that the question is largely one of price. Another factor is that there is only one firm who have hitherto produced this alloy, and that this firm (Peter Hooker, of Walthamstow) are at present in liquidation. Further work is necessary to develop the material, and at present larger firms are taking the matter up and no doubt supplies will be available at a more reasonable price in future, due to the larger quantities which will be used. There is no difficulty in forging or in heat-treating this material. There is one point to remember; it age-hardens more readily than duralumin.

Mr. VOWDEN, A.I.D., asked whether the lecturer would say what happens exactly to the structure of a steel plate when it is bent, and then as to what change takes place when that bent steel is normalised.

Mr. WILLIAMS then showed a slide which clearly indicated striations along the bend of a piece of plate, and it could be seen that the striations or layers had slipped and the pearlite had tended to segregate into lines. On the outside of the bend the pearlite could be seen to be separating. The next slide showed the same sort of plate after normalising at 850°C., and it was noted that the striations had asserted themselves. A structure so restored is not an ideal structure, as it is not possible to entirely recondition the material.

Mr. TAYLOR asked whether in dealing with nickel-chromium alloys which are normalised beforehand it is necessary to cool right down or whether you can let it down to normalising temperature only.

Mr. WILLIAMS answered that it was necessary in the case of large articles to let it well down below this temperature in order to ensure that the crystals had the necessary time to re-form, particularly bearing in mind that with the larger articles the centre of the material maintains the heat much longer than the outside. If dropped to below 600° the part would then be dark red. With light steel fittings it would of course not be necessary to allow so long a time and the temperature could be dropped to 750° and then reheated.

The meeting closed with a hearty vote of thanks to the lecturer.

THE ROYAL AERONAUTICAL SOCIETY

Aims

The Royal Aeronautical Society exists for the furtherance of the Science of Aeronautics. It acts as the professional society or institution of qualified aeronautical engineers, conferring a recognised technical status on those qualified. The Society also organises discussions and publishes papers on subjects of importance in connection with the various branches of aeronautical engineering; encourages and assists technical students who desire to adopt the aeronautical profession for their careers; and provides an organisation wherein all interested in aeronautics, though not necessarily professionally connected with aviation, may meet together and have opportunities to keep themselves in touch with aeronautical affairs.

Membership

Membership of the Society is divided into the following grades:—

(*a*) **Students**: Persons under the age of 26 who are receiving a technical training such as will fit them in due course to become Associate Fellows.

(*b*) **Associates**: Persons employed in a technical capacity in the manufacture or operation of aircraft, who have had considerable experience in aeronautics but are not qualified to become Associate Fellows or Fellows. Entitled to use the letters A.R.Ae.S. after their names.

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Members in any of the above grades are entitled to attend the Society's lectures, receive the monthly JOURNAL free of charge (except Associates paying £1 1s. a year subscription) and consult and borrow books in the Society's Library. All grades, except Students, have full voting powers.

Activities

From October to April the Society holds a series of fortnightly meetings at which important papers are read by the leading authorities on aircraft design, operation and progress. All grades are admitted free to all these lectures, and tickets are issued to their friends on application to the Secretary. The lectures of the Society are reported in full in the JOURNAL, published monthly, which also contains important papers on aeronautical progress, and a regular epitome of the Society's activities. A classified list of articles which have appeared in the JOURNAL since 1917 may be obtained on application. Original papers of a fundamental character to the Science of Aeronautics are published from time to time as "Transactions of the Royal Aeronautical Society," and other important papers and reprints are also published.

The Society's Library is one of the finest aeronautical libraries in the world, containing many exceedingly rare aeronautical books, as well as being kept up to date. It is open to all members from 9.30 a.m. to 5 p.m. on weekdays, and 9.30 a.m. to 12 noon on Saturdays. The Library also contains the leading aeronautical and engineering papers of every country in the world.

The Society has a large collection of slides which are loaned to members for lecture purposes.